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The Windscale Incident

FOR the past six years the two Windscale reactors have been the main source of plutonium for the military atomic energy programme. Situated on the Cumberland coast, these two reactors were built as plutonium producers only and cannot be used for generating electricity. The power of the two reactors has never been disclosed, but it can be taken that they are bigger than the reactors installed at Calder Hall. They are air-cooled graphite-moderated natural uranium systems with horizontal fuel channels. Although based on experience acquired during the building of BEPO, the reactors operate at positive pressure, cooling air being blown through the reactors by large fans from where it is led to 400-ft stacks with filters at the top.

On October 11, it was announced by the U.K.A.E.A. that on the previous day overheating had been detected in one of the channels of No. 1 reactor while the reactor was shut down and the temperature had risen sufficiently for some combustion to take place. This was finally quelled by water spraying from the top of the reactor. Emergency measures were immediately taken to safeguard staff and health physics teams have been working in the surrounding countryside checking the released activity. As a result of measurements made on the radio-iodine content of milk, distribution from a limited area was prohibited, this later being extended to cover 200 square miles. The half-life of iodine-131 is relatively short (eight days) and these measures are only temporary. Preliminary measurements have indicated that the deposition of the more unpleasant fission products such as strontium and caesium has been negligible.

The full assessment of the total activity release will take some time to evaluate and final figures can only be approximate. It is likely that diagnosis of the cause of the accident will be a lengthy procedure and it is quite possible that no absolutely certain conclusions will be reached. It should be practicable, however, to develop a reasonable theory which will fit the results. Following a similar accident in France in October, 1956, no complete theory of the cause could be evolved although it was a reasonable inference that the fire developed as the result of a temporary blockage in a fuel channel. Similarly when NRX became supercritical in 1952, many months elapsed before the full chain of events could be analysed.

From the meagre information available at the time of going to press, the filters at the top of the stacks have clearly played an important part in limiting the spread of the more noxious radio-isotopes. It should be emphasized, however, that this type of accident can only affect the surrounding population with a coolant system of the type used at Windscale whereby the primary circuit is an open circuit and the coolant gas is discharged directly to the atmosphere. A similar accident, say at Calder Hall, could be extremely expensive to put right and could put a reactor out of operation for a protracted period of time, but unless it were accompanied by a major mechanical catastrophe, the damage would be confined to the reactor circuit.

From the precautions that have been taken, it is quite clear that the Atomic Energy Authority is determined to allow no possibility of excessive dosages being received by the surrounding population. Although the reported activity level in milk, viz. six times the m.p.l., represents a significant iodine content, there is very little doubt that drinking milk with this radio-active concentration could cause no organic harm to adults when taken in conjunction with the limited time factor involved. It is also unlikely that children would really be harmed by drinking the milk, but the A.E.A. is ensuring that no precautionary measures, however exaggerated they may seem, are left untaken. Apart from the feeling of trust that this must inspire in the Authority's sense of responsibility, the Authority is also protecting itself against possible wild-cat damage claims that may arise in the future. It is, of course, imperative that the body responsible for advising on maximum permissible levels and for establishing codes of good practice should be most scrupulous in seeing these are observed to the letter.

The siting philosophy that has been adopted by the A.E.A. has periodically been brought into question, but this accident at Windscale serves to point very forcibly the value of a remote location for such plants. There is little doubt that if the reactor concerned had been located in a more densely populated part of the country, no real population hazard would have resulted, but the complexity of monitoring, checking and decontaminating would have been multiplied by enormous factors. Because of its position on the coast of Cumberland, problems have been confined to an area that can be fully investigated at all times of the day and the population that could conceivably be affected can be supervised to a degree that would be impossible in a built-up area.

The accident at Windscale will be a costly business but the experience which it will provide from the examination of the results of this uranium fire can be of considerable value when applied to future designs. It has been emphasized that such an accident could not happen at Calder or the nuclear power stations as far as the public is concerned, but it is not impossible for somewhat similar fires to develop even in the carbon dioxide atmosphere of a power reactor. In terms of lost output and repair costs, such a fire would be extremely expensive and if the fire at Windscale provides data which in any way reduces the possibility, then at least some good will have come of it.

Irresponsible comparisons have been drawn to atomic bomb explosions, using figures of very doubtful value; it is almost impossible to compare this release of activity from the stack at Windscale with the explosion of an atomic bomb. Quite apart from the fact that the released activity is different by many orders of magnitude in the two cases, the difference between a slow release resulting from burning and an instantaneous release from a bomb cannot be over-estimated. Furthermore, such comparison ignores the very large prompt gamma radiation from a bomb and takes no account of the action of the filters at Windscale of the relative biological effectiveness of the various types of radio-isotope, or the many factors which govern the concentration of deposited activity.

One lesson that must be learned from Windscale is that six years' experience does not automatically imply infallibility. Whether the results of the enquiry irrevocably define the cause or not, Windscale indicates how many are the unknowns and how easy it is for something to go wrong. The phrase " one cannot be too careful " will always be apt in reactor construction and operation. The fire may indicate also that we have still some way to go in the development of detection equipment of adequate sensitivity and speed response. It must also call in question the provision that has been made in the past for dealing with such emergencies and may well indicate that it would be a worth-while investment to build-in fire fighting equipment.

We may well regret that when the French reactor G1 overheated causing combustion of a major proportion of one uranium channel that we were not as co-operative as we might have been and were not willing to exchange our experience of canning techniques for a detailed examination of the French reactor while it was shut down. Assistance from the team which examined G1 and subsequently repaired it would no doubt be of considerable value at Windscale. Provided they are willing at this late stage to co-operate it would seem a wise thing to seek advice from the French engineers. It is also not generally appreciated that the Hanford piles have not been free from this trouble and a number of fires have occurred. A valuable exchange of information with both France and the U.S.A. should not be bedevilled by excessive security restrictions.

It is interesting to observe the reaction of the general population at such a time and, although the British are renowned for their phlegmatic approach to unusual situations, some credit must be paid to the A.E.A. for its willingness to take the public into its confidence and for its trust in the good sense of the population as a whole. It is likely that questions at future power station siting discussions will be more pointed and perhaps pressed with greater energy than heretofore, but it seems unlikely that the Windscale release will affect our power reactor programme on anything like the same scale as the credit squeeze.

The Nautilus Visit

THE visit of the Nautilus to Portland and Plymouth harbours has raised some interesting questions on docking authority for a nuclear-powered vessel. In effect the Nautilus power unit is the first power reactor that has been installed near a built-up area in the United Kingdom and one would have expected that before this step was taken, even more stringent investigations would have been made than are undertaken for the construction of the civilian power stations at the relatively more remote sites such as Berkeley and Bradwell.

While no international body is capable of assuming responsibility for the safety of a nuclear-powered ship, the hazard assessment must remain a national responsibility; it must still in part remain a national responsibility even after international authorization. We are assured that both the Admiralty and the A.E.A. after due consultation were confident that the Nautilus represented no population hazard, but on what was this assurance based? It would appear that the Reactor Safety Committee had no opportunity of officially considering the power plant and furthermore had little detailed information on which to base an assessment. In addition, as we in this country have no experience of water moderated reactors, would an academic assessment of the safety of the plant be really meaningful? Admittedly the Nautilus has operated without mishap for two years but it is pertinent to note that Windscale had operated perfectly satisfactorily for six years.

The stay was, of course, temporary and the Nautilus has departed without incident, but if the Reactor Safety authority in this country is to take its responsibilities with the seriousness that it must, then there must be no suggestion that its authority is to be by-passed because of political expediency, or that other opinions are to be sought (such as the U.S.A.E.C.) as an alternative to supplying detailed information.

The visit of the Nautilus did, of course, provide an opportunity for many people to see the submarine power unit who otherwise would have had to rely on second-hand information. The inspiration that this has given, quite apart from a certain superficial knowledge, will be of considerable value in our own ship and submarine programme. But, reactor safety and population protection are not matters which can be discarded for convenience. They must be taken with deadly seriousness at all times.

Commentary

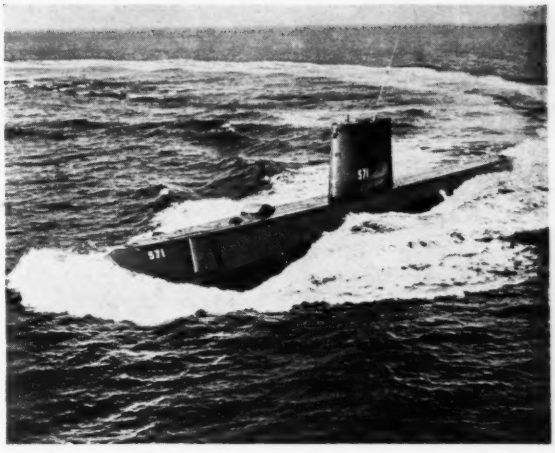
U.S.S. Nautilus

Now that the N.A.T.O. exercises have been completed, people in the United Kingdom have had an opportunity of seeing at least the outside of the Nautilus, the world's first nuclear-propelled ship, operated by the U.S. Navy. She is 319 ft long, 28 ft in the beam, displaces over 3,000 tons and has a normal complement of 11 officers and 85 men. Since its first basin trials the Nautilus has put up a remarkable record of underwater operation. Before its first refuelling period in April the ship had covered 62,560 miles, 36,498 of which were under water. Since refuelling, 33,000 miles have been added to the log, over 80% of it under water. The Nautilus would appear to be the first submarine which has been designed specifically for underwater running as against occasional underwater operation. Whereas oil-fuelled submarines had underwater speeds which were limited in practice to 3 or 4 knots, the Nautilus is known to have a maximum speed in excess of 20 knots. The real full-out speed has not been divulged and it is possible that the 20-knot figure is a very conservative estimate of the maximum performance. At the same time the hull design does not represent the optimum hydrodynamic surface that can be achieved.

The Nautilus is powered by a pressurized water reactor which generates steam in two heat exchangers, the steam then driving two conventional turbines and twin screws. The core of the reactor is mounted vertically in a stainless steel-lined carbon steel pressure vessel, the fuel elements being Zircaloy-clad uranium-zirconium alloy, the uranium being highly enriched, probably to the extent of about 40%. The primary circuit is of stainless steel and the general philosophy of design that has been adopted has been one of surety of operation and long life rather than economy; novel constructional features have been kept to the minimum. Control rods are mounted vertically and can be operated either manually or automatically. By use of stainless steel throughout, difficult welding joints have been largely eliminated, although some transition welds are undoubtedly required. Otherwise the circuit appears to be remarkably flexible and no operational limitations have been imposed on thermal cycling or load variation.

The main reactor shielding is of lead and polythene—polythene being chosen in preference to water because it can be readily cut to shape and rigidly mounted in places of difficult access whilst the construction of complex water tanks is a hazardous procedure and gasification from the water an additional complication. Fuel oil tanks have, however, been used as additional shielding in certain external sections of the primary circuit. The ship is fitted with two 300kW Diesel-electric generators capable of supplying hotel services in the ship and of feeding an electric motor on each shaft which will propel the submarine at a speed of a few knots should a major breakdown in the reactor occur. Auxiliary power is normally derived from four turbo-alternators fed by the reactor. Facilities are not provided for fuel changing en route and whilst it is believed that a minor fuel element failure could be tolerated, no experience of such a failure has been gained to date.

One of the outstanding features of the Nautilus unit has been the trouble-free operation of the power plant. Some troubles have, of course, been experienced; these are inevitable with any major project but it is interesting to note that these have been entirely confined to the conventional side of the plant and no operation failures whatsoever have been encountered with the reactor itself.



The power unit seems to be remarkably flexible in operation. Whilst automatic control of the rod position is provided, it is normal to run the submarine on manual control. Speed variations are made by adjustment of the turbine throttle valves and the negative temperature coefficient in the reactor is such that the reactor tends to be self-regulating. The reactor operator will probably follow the steam setting manually but this trimming is not vital and is only a refinement. Taking load off the turbines does of course increase the primary circuit temperature and speed variations therefore do cause a variable temperature particularly in the return side of the primary circuit. As mentioned earlier, no limitation has been imposed, however, on the thermal cycling of this part of the circuit and no trouble is anticipated in operating the power unit in this manner. The primary coolant flow is maintained by glandless pumps. The thermal capacity of the primary side is relatively small so that if the safety rods are pushed home, drive from the turbines is lost almost immediately.

At least in the cold, clean, unpoisoned state sufficient excess reactivity is invested in the core for start-up to be possible at any period after shut-down, but towards the end of the life of the fuel elements—burn-up figure in terms of the MWd/ton is not divulged—some slight limitation due to zenon build-up may be imposed. If it were necessary to overrun the reactor in terms of burn-up, build-up could be kept to a reasonable value by maintaining the reactor critical and dumping the slight excess power. A number of alternative coolant systems are installed for shut-off running and for emergency cooling. We have had lengthy discussions with the ship's Commander and clearly the power unit is delightfully easy to control and gives as much flexibility as could be desired. From cold, full power can be developed within a period of two hours, a figure which

compares well with any propulsion unit in which steam is the working substance.

During its 100,000 miles of operation the Nautilus has carried out a great number of practice manoeuvres and dives including operation under emergency conditions. The diving angle and the surfacing angle is as much as 30° and due to the shape of the hull, when running on the surface the ship is subject to considerable rolling and some pitching. The plant has, therefore, been required to operate under fairly strenuous conditions and whilst under-sea running is akin to land base conditions, sufficient experience has been gained to give considerable confidence in the design of future special features such as control mechanisms and structures carrying heavy weights subject to accelerations in a variety of planes.

From the health hazard point of view the Nautilus has provided also considerable experience in the operation of a reactor under closely confined conditions. Shielding has, on the whole, been of conservative design and the direct and induced radiation from the reactor core has caused no embarrassment. On the other hand it has been found that after prolonged running under water, radon build-up from luminized dials and gauges can be significant and the decision has been taken to eliminate radium-activated fluorescent materials from the ship. The appreciation of this aspect of radiation hazard and the steps that have been taken to eliminate it give some measure of the care that has been taken in the monitoring of radiation in the submarine.

Although no official cost has been published for the power generated by the Nautilus reactor, it is probably in excess of 50 mill/s.h.p.,h. and may be as high as 100 mill/s.h.p.,h. This in terms of conventional power costs is high and the question is therefore relevant as to the value of a ship of this nature. In the first place, of course, being a war vessel, costs are of secondary importance unless they represent a very real drain on the nation's essential reserves. The U.S.A. has a considerable stock of enriched fuel and although fabrication costs are high, these do not represent a real drain on the country's resources. The situation with a merchant ship is, naturally, entirely different. The most important aspect however of a nuclear submarine is that because of its very great range, its complete independence of air supply except for the small amounts consumed by the crew, its potential use as a base for guided missiles, the ship is not just an advance on the conventional submarine, but is in fact a new weapon. So great an importance is placed upon the strategic value of a completely independent striking weapon by the United States Government that nineteen of these vessels have been ordered. The case for the nuclear-propelled surface ship is not so clear-cut and nuclear propulsion although obviating the necessity for relatively frequent refuelling represents only a marginal improvement over the conventional type. As a result, the present United States Government policy appears to call for the construction of one of each major type of surface vessel and, until operational experience has been obtained, it is unlikely that any large expansion of this constructional programme will be made. The most impressive ship in this class is, of course, the aircraft carrier which will be powered by 8 pressurized water reactors.

The Nautilus is the first of the nuclear submarines; the second, the Sea Wolf, which began sea trials at the beginning of this year, is sodium cooled and gave repeated trouble in the super heater section although it is now believed to stem from the water side rather than the sodium side. Further developments of this type of plant have been abandoned and the navy is to install pressurized water reactors only. In hull design, however, significant advances are likely to be made over the Nautilus and the results of trials made on the conventional-powered submarine with an unconventional hull have indicated that considerable improvements can be made in the hydrodynamics of the shell and there appears to be no technical reason why a speed of 100 knots should not be attainable. Furthermore, with proper design, the curve of power against speed would still appear to be reasonably flat at such a speed and power requirements therefore would not be phenomenally large.

The Vienna Conference

In view of the persistent tension in world affairs and the regular flaring up of the cold war between East and West, the first meeting of the International Atomic Energy Agency can be viewed with cautious optimism. Although at the first meeting some of the traditional bones of contention were brought out, such as the inclusion of Nationalist China as against Communist China, the general atmosphere of the conference was reasonably cordial. One of the critical issues from which the tone could be assessed concerned the appointment of a Director-General. Until the last moment it was expected that a neutral opponent to Mr. W. S. Cole of the United States would be proposed by the U.S.S.R. to force the vote, but the Russian delegate was content when it came to the issue to state his government's preference for a neutral Director-General and leave it at that.

In terms of practical results, the preliminary session could not be expected to achieve more than the establishment of committees and terms of procedure. It is unlikely also that by the end of the sessions the general conference will have been able to do much more than comment on the preliminary findings of these committees. Certain firm offers, were, however, made to the agency in the first session chief amongst which were 5,000 kg U^{235} by the U.S.A. followed by an additional proposal to match all offers made by other countries by July 1, 1960. Contributions of 50 kg and 20 kg contained U^{235} by the U.S.S.R. and the United Kingdom, respectively, completed the enriched fuel total. Natural uranium with a U^{235} containment of 700 kg was offered by Portugal.

At the present time, however, it must be pointed out that the agency has no clear ideas on how this material should be used. Its preliminary objectives will be largely concerned with education and with the training of the less developed countries in the use of fissile materials and the application of radio-isotopes. The agency intends to set up its own establishments and to acquire equipment, but the extent of this investment will depend upon the facilities offered by individual countries and on the general economic structure.

The most thorny problem in the operation of the agency will concern safeguards to ensure that fissile material is used for peaceful purposes only. At one stage of the conference it looked as if this would present a major stumbling block right from the first, but as those countries with an existing military programme will not be on the receiving end for some time the matter was left on the table.

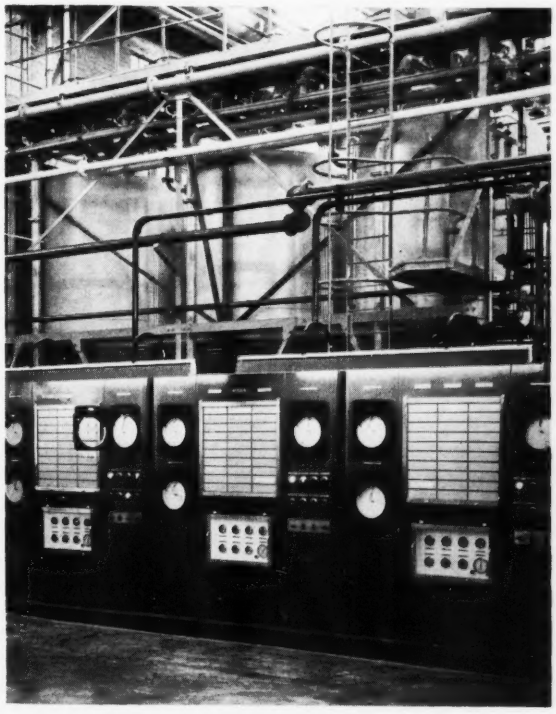
The ultimate value of the agency has yet to be proved but at least it has provided another platform where nations of the world can get together to discuss subjects of common interest. Provided that the discussions can be maintained on a reasonably technical level and do not become a propaganda platform for international politics the agency can make a real contribution to world knowledge and world peace.

Uranium in South Africa

By PETER HOLZ

URANIUM is already making a significant contribution to the economy of South Africa. So far no high grade ore has been discovered, but exploitation of the low grade material found in most gold bearing strata has enabled South Africa to establish itself as one of the world's leading producers. There is at present no internal market for fissile material and the total production is exported to the U.S.A. and the U.K.

The first identification of radio-active minerals in the conglomerate deposits of the Witwatersrand—the gold-containing deposits of the "Ridge of White Water" on which Johannesburg with its richest gold mines in the world is situated, took place in 1923, but it was 18 years later, in 1941, that Dr. G. W. Bain, Professor of Geology at Amherst College, Massachusetts, U.S.A., paid a brief visit to South Africa, and took back to America a number of ore samples which he had collected in Witwatersrand gold mines. They were put in his laboratory and forgotten until he became consultant to the Manhattan Project, atomic bomb undertaking established before the present United States Atomic Energy Commission was created.



Ion exchange column and control panel at Vaal Reefs Exploration and Mining Co., Ltd.

Following a report on these samples, the Governments of the U.K. and U.S.A. approached the Union Government in 1945 about the possibility of extracting uranium from gold ores. Further tests indicated that uranium was far more widespread in South African gold ores than formerly realized.

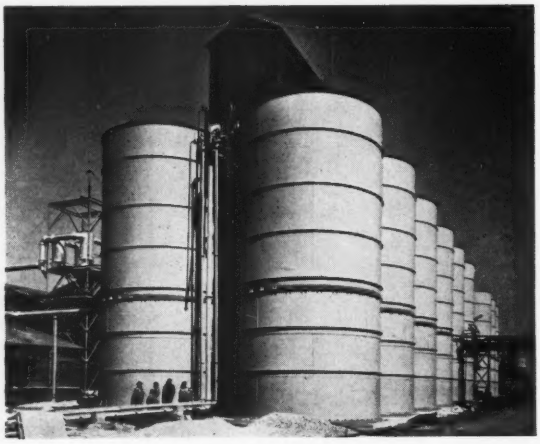
By 1950 the newly created South African Atomic Energy Board and the Governments of the United Kingdom and the U.S.A. had entered into an agreement providing for the large-scale production of uranium by West Rand Consolidated Mines Ltd., Daggafontein Mines Ltd., Blyvooruitzicht Gold Mining Co., Ltd., and Western Reefs Exploration and Development Co., Ltd. Soon afterwards the West Driefontein Gold Mining Co., Ltd., and Stilfontein Gold Mining Co., Ltd., were added to the list of uranium producers. All these companies were then authorized by the Minister of Mines, acting under the Atomic Energy Act, 1948, to undertake the production of uranium. Today seventeen full-size plants have been authorized to treat the output of twenty-nine of South Africa's gold mines. Of these seventeen plants, sixteen are already in production and in 1956 produced 8,726,308 lb uranium oxide.

Health Hazards

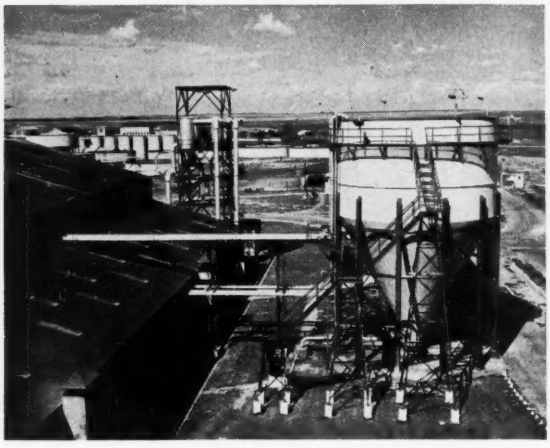
Some years ago, officials of the Council for Scientific and Industrial Research made underground observations in three mines to determine whether radon gas occurred in the workings, and whether particles of uranium in the air were present in significant quantities to be of any harm. The result of the tests indicated that there was no trace of radon gas present and that the dust samples taken showed no sign of radio-activity of a dangerous level.

Extraction

The work of the uranium plant begins when the gold has been extracted from the finely-crushed ore. The gold ore residue is received at the uranium plant on a conveyor belt and, in the first stage of the process, the material is fed into a tank where it is agitated with a mixture of diluted sulphuric acid to produce a pulp, which is then pumped into tanks for leaching with additional sulphuric acid and manganese dioxide. Here, the uranium content, as well as some other constituents, are dissolved. Separation of the uranium-bearing solution from the solid particles is achieved in a battery of rotary filters. The next step is the recovery of the uranium content from the filtered acid solution. It would be possible to do this by neutralizing the acid with an alkali, but this method would result in the precipitation not only of uranium compound but also most



(Left) Pachuca stock tanks at Western Reefs mine in the Transvaal. (Below) Pachuca stock tank at the President Steyn mine in the Orange Free State.



of the impurities, and would produce a very low-grade concentrate, unsuitable for marketing. An alternative system has been developed utilizing the ion exchange process. In the plant, uranium ions from the pregnant solution are selectively absorbed on to a synthetic resin contained in ion-exchange columns. After a time the resin bed becomes saturated with uranium, which is removed by nitric acid, the liquor being neutralized with ammonia. The bright yellow precipitate thus obtained is collected and conveyed by road tank wagons to a central drying and calcining plant built at a cost of £1½ million in the neighbourhood of Johannesburg. The granular U_3O_8 produced is eventually drummed and shipped to the U.S.A. and Great Britain.

Plant Manufacture

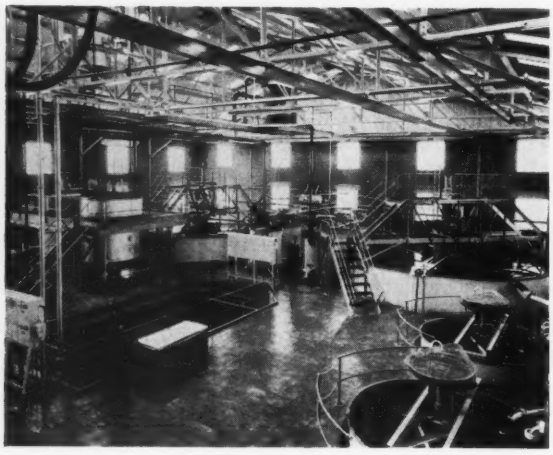
Most of the plant for the production of uranium from gold slimes residues has been made by South African manufacturers. Long-term contracts with the official purchasers of U_3O_8, i.e. the United Kingdom and the U.S.A., have enabled the erection of uranium recovery and acid plants to be financed. The ultimate total value of these will be in the neighbourhood of £75 million. The cost of erection of these plants is covered by loans from the purchasers, repayable out of the profits of the sale of uranium.

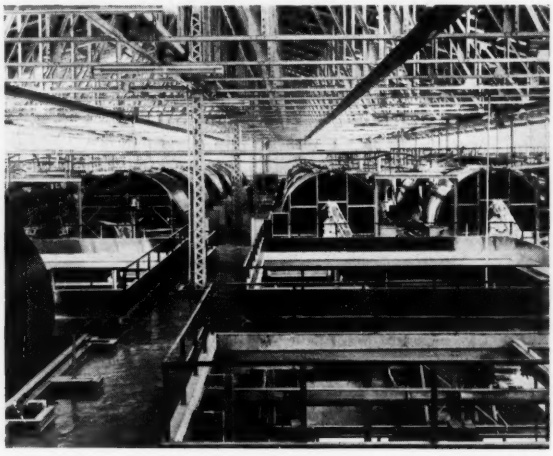
Much of the equipment used in South African uranium plants is rubber-lined due to the acidity of the process. The rubber lining is done locally, as is also the fabrication of stainless steel parts for pumps, rotary filters and valves. A multitude of sumps and trenches had to be acid-proofed and this was done by using bricks of local manufacture.

Costs

The final capital cost of a uranium plant can be deduced from the figures established for the West Rand Consolidated Mines—by no means the biggest producer—whose rated capacity is 70,000 tons of slimes per month.

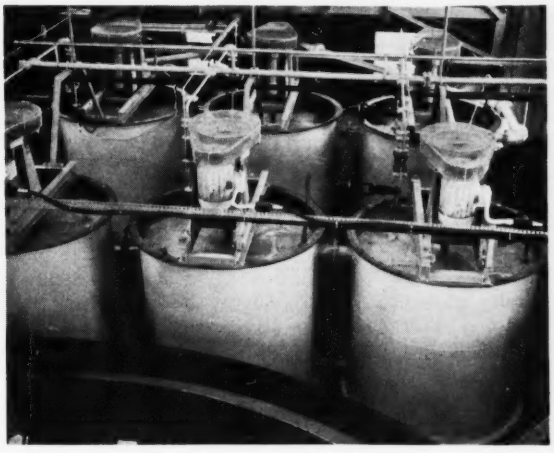
Conveyor carrying slime from gold plant to uranium plant, including glue preparation plant and storage	£45,000
Complete uranium plant, including all buildings and foundations	£1,257,000
Storage and preparation of lime and manganese reagents	£117,000
Sulphuric acid plant	£540,000
Water supply	£19,000
Power supply	£40,000
Rubber shop and equipment	£3,000
Change house and offices	£38,000
Roads and fences	£21,000
Housing	£136,000
Laboratory	£26,000
Workshops	£20,000
Preproduction expenditure	£30,000
Total	£2,292,000





(Above) Rotary filters in the President Steyn mine. (Left) The precipitation room at Vaal Reefs.

(Right) Pilot leach plant at the Western Reefs mine. (Below) Agitator tanks where the lime is added, at Vaal Reefs.

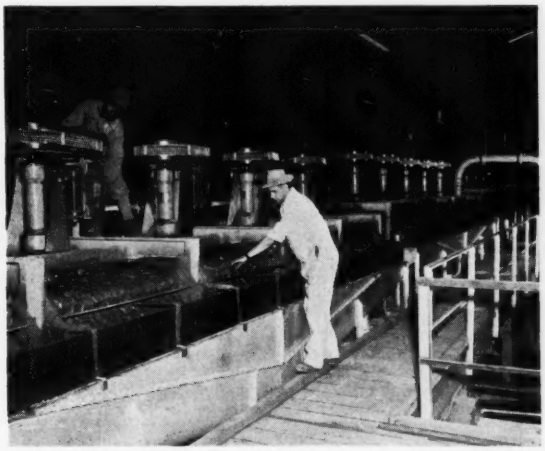


It may be as well to mention here that as far as sulphuric acid is concerned, as this particular mine has been producing pyrites for many years, it was decided to build a sulphuric acid plant to utilize part of it; 1,300 tons of concentrated sulphuric acid are used monthly at West Rand Consolidated Mines Ltd., in addition to 900 tons of manganese dioxide (for leaching), 1,000 tons of lime and 9 tons of glue (as a filter aid).

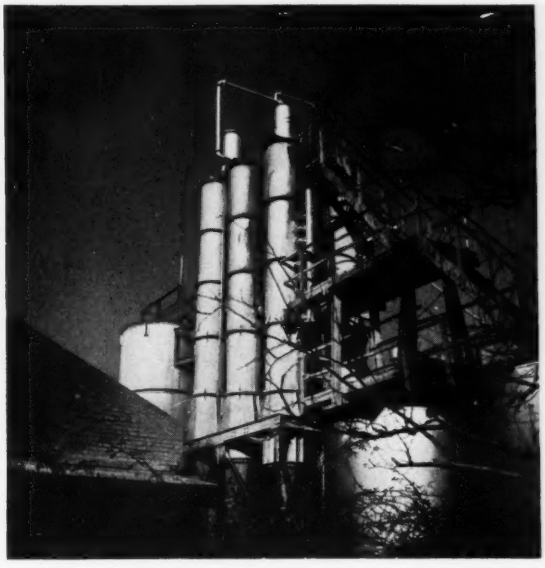
The maximum demand for electric power and the average monthly figure of units consumed at this mine can be taken as shown in the following tabulation.

	Maximum demand kVA	Consumption kWh
Uranium plant	1,300	800,000
Acid plant	500	300,000
Total ..	1,800	1,100,000

The maximum demand for electric power for the operation of these units can be taken as approximately



(Above) Operator adjusting flotation cells in which the pyrites is concentrated, at Daggafontein Mines. (Right) The "candle" filters which separate the sludge from the uranium-rich solution at the President Steyn mines.

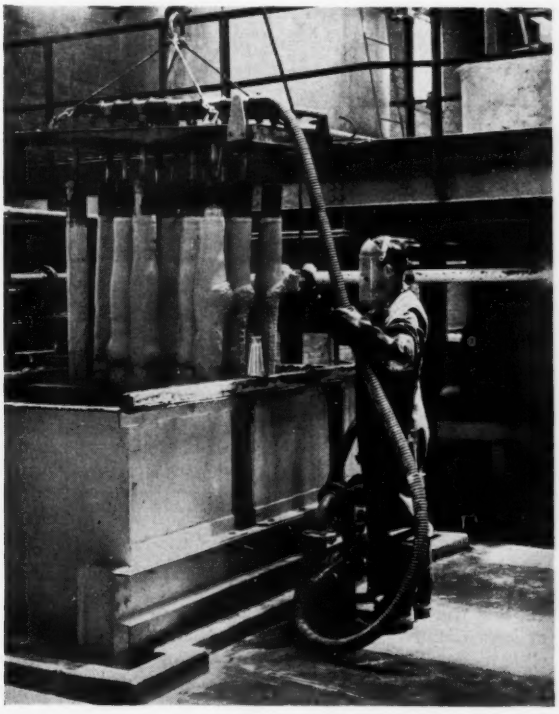


1,800 kVA, while an average monthly figure of units consumed is about 1,100,000.

The basic design for the S.A. plants was determined by a sub-committee of the Transvaal and Orange Free State Chamber of Mines[1] to which most mines belong. The committee consists of consulting mechanical and electrical engineers as well as consulting metallurgists of the various mining groups participating in this project.

Progress

The drawing office stage of South Africa's first uranium plant was reached in December, 1950. Twenty-one months later the first uranium plant was in operation. In 1953, a



Operator at the Daggafontein Mines taking a sample of uranium oxide from a storage tank.

year after the first uranium plant was started, the value of export of prescribed materials (largely uranium oxide) totalled £3,900,000. In 1954 the value increased to £14,800,000. In 1955, exports rose to £30,000,000. Last year brought in more than £40,000,000 and although no official statement has been issued about the price paid by both Great Britain and the United States of America, economic experts put the figure at about £3 15s. per pound.

It has meanwhile been announced that in view of the growing importance of atomic energy development in South Africa, the Atomic Energy Board may grow to become a State Department, as South Africa has assumed such a vital new rôle in world affairs as one of the principal suppliers of uranium, comparable official figures being shown in the table.

URANIUM OXIDE PRODUCTION

Country	1955 tons	1957 (estimated) tons	1958/9 (estimated) tons
Canada	3,300		14-15,000
United States	6,000	10,800	14,000
South Africa	4,400	6,000	

On the basis of known information it is estimated that South Africa has 1,100 million tons of indicated uranium ore reserves with a uranium oxide content of 370,000 tons. Both figures are well above those of the United States and Canada, where the reserves of uranium oxide are estimated at 174,000 tons and 240,000 tons respectively.

South Africa is already playing an important rôle in the field of nuclear research and development, besides producing uranium and thorium on a large scale. Three particular examples of this are the Union's work in helping to set up the International Agency for the Peaceful Use of Atomic Energy, the achievements of the South African Council for Scientific and Industrial Research in Pretoria and the work of several South African universities, in particular the University of the Witwatersrand in Johannesburg and the University of Pretoria.

The Council for Scientific and Industrial Research, a Government organization, has done pioneering work on nuclear research in South Africa and has built a 16 MeV cyclotron at a cost of £230,000 to undertake fundamental and applied research in this field. This cyclotron is the first to have been built anywhere in Africa. Major components of the unit were manufactured in South Africa and only items such as radio-valves, relays, vacuum pumps and measuring instruments were imported from overseas. The magnet has a pole diameter of 44½ in. and weighs 84 tons, complete with its coils.

The manufacture of heavy water in South Africa has also been given serious consideration, particularly since SASOL, the new South African Oil from Coal plant, has made certain chemicals available, which are necessary for heavy-water manufacture. This would be a £2-3 million industry at current prices. It is believed that as a result of various factors, South African heavy water would be cheaper than that manufactured abroad. Certainly the vast coal deposits of South Africa which can be mined at very low cost could provide a very cheap source of primary energy for the production of heavy water, the market price of which is heavily dependent upon energy costs.

Acknowledgment is made to the Anglo-American Corporation of South Africa, Ltd. and the Transvaal and Orange Free State Chamber of Mines for the illustrations to this article.

Footnote

[1] Sixty-five gold mining companies (including 22 uranium producers), 24 coal mining companies and 13 financial corporations form the ordinary membership of the Transvaal and Orange Free State Chamber of Mines.

Each of these companies has its own board of directors, each has its own body of shareholders; each company functions as an autonomous business undertaking.

The need for certain services is, however, common to them all; services that can, conveniently and economically, best be provided on a co-operative basis by a central organization. To this end, these companies sponsor and direct the Chamber of Mines, which has no administrative authority over its members, but exists to serve them all, and in general, to advance the interests of the gold, coal and uranium mining industries.

La Production de l'Uranium en Afrique du Sud

Bien que la connaissance des minerais d'uranium en Afrique du Sud remonte à plus de 40 *ans, ce ne fut qu'en* 1945 *que les gouvernements du Royaume Uni et des Etats-Unis s'adressèrent à l'Union Sud-Africaine au sujet de l'extraction de l'Uranium des minerais d'or. A l'heure actuelle,* 17 *installations de grandeur intégrale sont en fonctionnement. L'article contient une brève description du procédé d'extraction et donne quelques indications du coût de l'installation de traitement. On y donne aussi une comparaison des divers niveaux de production de l'uranium dans différentes parties du monde. A un certain moment, l'Afrique du Sud était le plus grand producteur du monde, mais tant aux Etats-Unis qu'au Canada les taux de production augmentent rapidement.*

Urangewinnung in Südafrika

Uranerze hat man schon vor mehr als 40 *Jahren in Südafrika gefunden, aber erst im Jahre* 1945 *traten die Regierungen der Vereinigten Staaten und Grossbritanniens an die südafrikanische Union mit dem Vorschlag heran, Uran aus Golderzen zu gewinnen. Heute sind bereits* 17 *Grossanlagen im Betrieb. Eine kurze Beschreibung des Gewinnungsverfahrens wird durch einige Angaben über die Kosten der Anlage ergänzt. Es folgen einige vergleichende Zahlen über die Urangewinnung in anderen Weltteilen. Eine Zeitlang war Südafrika der grösste Produzent, neuerdings steigt aber die Gewinnung in U.S.A. und Kanada sehr schnell an.*

Produccion de Uranio en Sud Africa

Aunque los minerales de uranio eran ya conocidos en Sud Africa hace más de 40 *años, no fué hasta* 1945 *que los gobiernos del Reino Unido y los Estados Unidos se interesaron con la Unión sobre el asunto de la extracción de uranio de los minerales de oro. Hoy en dia existen en pleno funcionamiento* 17 *instalaciones de gran tamaño. El procedimiento de extracción se describe berevemente y se ofrece alguna indicación de los costos de instalaciones de tratamiento. También se hace cierta comparación de la producción comparativa en diversas partes del mundo. En una época, Sud Africa era el productor más grande del mundo, pero tanto en los Estados Unidos como en el Canadá, las razones de producción están aumentando rápidamente.*

PLUTONIUM—

and its Alloys

By K. Q. BAGLEY, Ph.D., B.Sc.
(Culcheth Laboratories, U.K.A.E.A.(I.G.))

Previous articles in this series have dealt with uranium and thorium. In this, the third article of the series, comparable data are given for plutonium. Again, particular attention is paid to compatibility, plutonium appearing to be even more reactive than uranium.

PRIOR to the realization that nuclear energy could be utilized as a source of power, plutonium had no reason to exist, and effectively did not exist. Its only applications concern the generation of nuclear energy either for civil or military purposes. It has no conceivable value as a material of construction either in the pure state or as an alloying addition to other metals. The occasions on which it can be used as a pure material are rare and in most applications it will be present as a minor constituent of the fuel alloys in which it is used.

Plutonium has a most important role to play in the production of nuclear power. Because of its formation by neutron capture of U^{238}, it acts as a stabilizer of reactivity in natural or near natural uranium reactor systems. When separated from irradiated fuels, the metal may be used as the initial fuel for further reactors in conjunction with natural or depleted uranium, thorium or a non-fissile material of low neutron capture cross section. Its uniquely high average yield of three neutrons per fission makes it suitable for breeding further fissile material, although its associated nuclear properties are such that this characteristic can be used to advantage only in fast fission reactor systems, i.e. systems in which the neutrons causing fission themselves possess high energy. It is the possibility that breeder systems employing plutonium may create many more fissile atoms than they destroy that promises to make this metal perhaps the most valuable of all fissionable materials in the future development of nuclear power.

OCCURRENCE AND AVAILABILITY

Although the isotope Pu^{239} has been detected in uranium ores to the extent of 5×10^{-12} of the uranium content[1] plutonium may be regarded for all practical purposes as a synthetic element derived from neutron irradiation of natural uranium. The element is formed principally from the reaction:

$$U^{238}\ (n, \gamma)\ U^{239} \xrightarrow[23.5\ \text{min}]{\beta^-} Np^{239} \xrightarrow[2.33\ \text{d}]{\beta^-} Pu^{239}$$

and plutonium extracted from fuel elements subjected to short periods of irradiation consists almost entirely of Pu^{239}. On longer irradiation this isotope absorbs neutrons and is converted progressively to more or less stable isotopes of mass number up to 243. Isotopes of mass number 232 to 238 formed by side reactions in the reactor core, involving U^{235} or neptunium are also known. In consequence of its mode of formation, plutonium may be considered indigenous to any part of the world possessed of the necessary technological resources and uranium supplies to build and operate nuclear reactors, and its synthetic abundance is limited only by the natural abundance of uranium. World supplies are at present small, and the cost of the metal, dictated by the cost of extraction and purification and its value as a fissile material, is of the order of tens of thousands of pounds per kilogramme. It may be expected, however, that as more and more reactors, particularly fast breeder reactors, are brought into production, the situation with respect to both availability and cost will be considerably improved.

EXTRACTION

The starting point for the extraction of plutonium may be considered as an irradiated fuel element, comprising uranium metal and some canning material. The irradiated fuel contains approximately equivalent weights of plutonium and a mixture of intensely radioactive fission products, together representing only a small fraction of the uranium mass.

When the aim is to produce pure plutonium entirely free from fission products and uranium, a "wet" chemical processing route is normally adopted. The first step is to store the fuel elements under water to permit decay of fission product activity. The decay period is preferably long enough to permit decay of the active fission product gases Xe^{133} and I^{131}, but is usually determined in natural uranium fuels by the time required for decay of Np^{239} to Pu^{239} or possibly U^{237} (formed by parasitic capture from U^{235}) to Np^{237}. After several months cooling, the element is stripped of canning material and dissolved in nitric acid. The nitrate solution so formed, containing uranium, plutonium and fission products is adjusted to the necessary acidity and fed into a series of mixer-settler units or columns where the following processes occur. (1) Separation. Uranium and plutonium (as U^{VI} and Pu^{IV}) are separated from the fission products by a solvent extraction process. In one process of this type, uranium and plutonium ions form complexes with tributyl phosphate (TBP) and nitrate ions which are then extracted by an organic solvent leaving the fission products in the aqueous phase. (2) Partition. Use is made of the variable valency of plutonium to separate plutonium from uranium, plutonium being reduced to the trivalent state which is washed out of the organic phase by dilute acid in a second extraction stage. (3) Purification. The plutonium is reoxidized to the tetravalent state and extracted once more

with TBP—kerosene solution, thus achieving further decontamination from fission products and uranium.

Each stage of the process is repeated as often as is required to obtain the purity of metal desired. The plutonium nitrate thus produced is backwashed from the organic solution into dilute nitric acid, concentrated by evaporation, and finally converted to the oxide. This compound may then be reduced directly to the metal by calcium, or may be first fluorinated with HF and the fluoride then calcium reduced. On a small scale, electrolytic reduction of a fused fluoride mixture may also be adopted.

It must be emphasized that because of the high fission product activity of the feed solution, all the initial processes must be carried out remotely behind massive shielding, and maintenance or modification of the plant once it has started to operate is difficult. At the same time, exceptionally high standards of metal purity are required:—

(i) to ensure that the β and γ radiation from the final metal is within the tolerance required for subsequent handling or fabrication,

(ii) to eliminate elements of high neutron absorption cross section, such as the fission products Gd or Sm, which would be undesirable in reactor fuel elements,

(iii) to eliminate lighter elements which on irradiation by α particles emitted from plutonium, are likely to produce neutrons, again introducing handling hazards.

Since the value of the metal is exceptionally high, the plant must continue to work at high efficiencies, of the order of 99.9% throughout its lifetime. Despite the stringent requirements of the processing procedure, plants of this type have been successfully built and operated both in this country and America.

In order to reduce the fuel hold-up implicit in the wet processing method as a result of the storage period required, pyrometallurgical methods of processing have recently been developed. In the simplest process of this type[2] irradiated fuel is melted in vacuo to remove volatile elements and then slagged, thus removing those metals more active chemically than plutonium, e.g. the rare earths; in practice these elements constitute the major fraction of the fission products by weight, neutron absorption cross section, and β or γ activity. This metal, from which the grosser effects of irradiation damage have been removed, may then be returned directly for fabrication into fuel elements by remote handling techniques. Alternatively, plutonium may be extracted from the decontaminated melt by a liquid metal, e.g. silver[3] or a fused salt, producing a more concentrated plutonium-uranium alloy of relatively low activity which may be further processed fairly cheaply or used immediately for the enrichment of natural uranium.

NUCLEAR PROPERTIES

The important nuclear properties of plutonium isotopes are shown in Table 1[1, 4]; σ_a, σ_f and σ_c denote absorption, fission and capture cross sections, respectively, expressed in barns; α is the ratio between the capture and the fission cross sections; η is the average number of neutrons produced per atom of plutonium isotope destroyed and ν the average number of neutrons produced per fission. It will be seen that despite the high fission yield, the η value for pure Pu^{239} is scarcely sufficient to ensure breeding in a thermal reactor system, assuming neutron losses in reactor structural materials. When contaminated by the non-fissile isotopes of mass number 240, 242, and 243, as will occur with prolonged irradiation of Pu^{239}, the η value drops below 2.0. On raising the average velocity of the neutrons, e.g. by raising the moderator temperature the η value for Pu^{239} falls yet again. In fast neutron systems, however, all plutonium isotopes are fissile, the α value is low and values of η are favourable for breeding operations.

The manner in which the fission product yield varies with mass number is shown in Fig. 1, along with the curves for U^{233} and U^{235}.

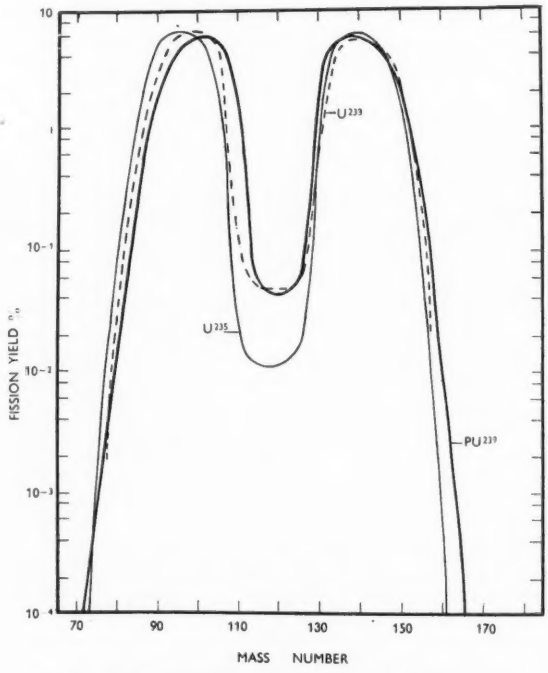


Fig. 1.—Fission yield for plutonium in a thermal neutron flux of given mass number.

All the plutonium isotopes are radioactive. Most of them emit α-particles, in particular Pu^{239}, whilst some emit low energy γ-rays or undergo K or L electron capture with X-ray emission.

PHYSICAL PROPERTIES

Crystal Structure and Phase Transformations

Plutonium exhibits six allotropic forms, α, β, γ, δ, δ' and ε, between room temperature and its melting point, 640°C. The crystal structures ascertained for each phase,[5, 6, 7, 8, 9] are shown in Table 2. The delta prime phase shows close structural similarities to the δ-phase, of which it may be regarded as a slightly distorted form, and its structure is commonly referred to as face-centred tetragonal. It is more accurately described as body-centred tetragonal with unit cell dimensions $a=3.327\pm0.003$Å, $b=4.482\pm0.007$Å at 465°C.[7, 8]

Phase transformation temperatures and volume changes on transformation are given in Table 3. Somewhat different values have been determined by other observers (e.g. Smith,[10] Ball[11] and Konobeevsky[12]) using similar experimental methods, and the Los Alamos values have been preferred largely because the material employed (99.8at.% Pu) was of higher purity than that available elsewhere (~ 99at.% Pu). The transition temperatures listed are those observed on heating at a slow rate. Appreciable hysteresis occurs on cooling even in the purest material available, and retention of other phases on cooling into the α phase appears unavoidable unless the material is cooled under high

pressures. Consequently significant volume contractions may occur in the α phase on standing at room temperature.

Density and Coefficient of Expansion

Recent values for the densities and linear coefficients of thermal expansion of plutonium phases are given in Table 4. All density values with the exception of that for the β phase were calculated from X-ray data. Partly due to the retention of higher temperature phases, partly due to the formation of micro-voids thought to be associated with phase changes,[15] dilatometric values are perhaps 2-3% lower than X-ray values. The 20% density decrease on heating from the α to δ phase and the 3% density increase on heating from δ to ϵ are exceptional, but it will be observed that practically no volume change occurs on melting.

The coefficients of thermal expansion listed are also calculated from X-ray data, and again show discrepancies with dilatometric values. An outstanding example is the value of $-120.10^{-6}/°C$ reported by Jette from dilatometric measurements in the δ' phase, compared with the X-ray value of $-(16\pm28).10^{-6}/°C$. Values obtained on cooling from the ϵ phase however are reasonably close to the X-ray figures. The negative coefficient of thermal expansion in the δ and δ' phases is unique in isotropic metals, and has not yet been satisfactorily explained.

Electrical Resistivity

The agreement obtained by a number of investigations (see Table 5) on the resistivity values for plutonium suggests that the high resistivity and the signs of the temperature coefficients are representative of pure plutonium rather than a result of impurities. The values reported are extremely high for a pure metal, and are similar to those determined for semi-conductors, but observed results do not follow the normal resistance-temperature relationships for intrinsic semi-conductors.

No data are available on thermal conductivity, but assuming that the normal Lorenz function applies, values in the neighbourhood of 0.01 cgs units at room temperature may be expected.

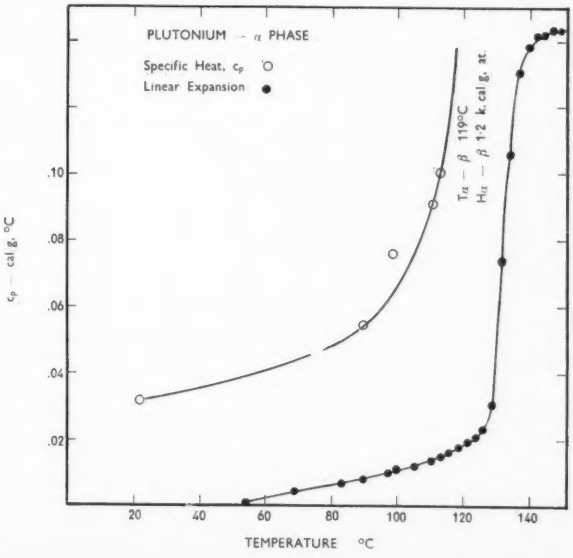


Fig. 2.—Variation in the specific heat of α plutonium with temperature.

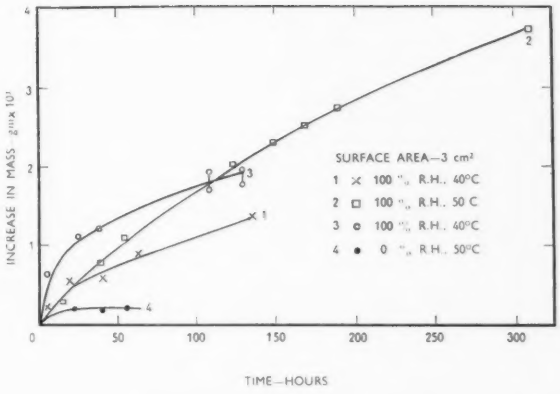


Fig. 3.—The oxidation of plutonium in air.

Miscellaneous

Values for the specific heat of α-plutonium recently determined by Dean and Kay[16] employing the self-heating effect of plutonium are shown in Fig. 2; the self-heating coefficient measured by Stout and Jones[17] viz. 1.923×10^{-3} W/g was used. The magnitude of the specific heat at room temperature $C_p = 0.032$ cal/g, °C ($C_p = 7.65$ cal/mole, °C) exceeds the value predicted from classical theory ($C_p = 6.4$ cal/mole, °C), the excess being attributed to an electronic contribution to the thermal energy. The latent heat of transformation $\alpha \rightarrow \beta$ was determined in the same investigation, the value obtained $\Delta H = 1.2$ kcal/mole, being in reasonable agreement with the value of 925 cal/mole reported by Sandenaw and Gibney.[13] The heat capacity of the α and β phases had been recorded by the latter as C_p (α) = 8.0 cal/mole at 25°C ; C_p (β) = 9.3 cal/mole at 160°C, from which the values C_v (α) = 7.3 cal/mole, C_v (β) = 8.7 cal/mole have been derived.

The vapour pressure of plutonium determined in the temperature range 1,100-1,500°C[19] fits the relation

$$\log_{10}P \text{ (mm Hg)} = (17{,}587\pm73)/T + 7.895\pm0.047 \quad (T = °K)$$

The average heat of vaporization in the same range was found to be 80.46 ± 0.34 kcal/mole, while extrapolation of the vapour pressure measurements indicates a boiling point of 3,500°K. An approximate value for the surface tension of liquid plutonium deduced from radiography of the plutonium meniscus,[14] was given as 100 dyne/cm. Predictions of the surface tension from known physical constants made by J. W. Taylor[15] lie in the range 490-580 dyne/cm. Data on magnetic susceptibility from different sources quoted by Coffinberry and Waldron[15] show considerable discrepancies both in values and the effects of temperature, possibly as a result of differences in the purity of the material examined.

Thermal Cycling

Repeated cycling of plutonium from room temperature into the delta or epsilon phases causes a progressive decrease in density with associated surface distortion similar to that observed on cycling uranium through its phase transition temperatures. The distortion in plutonium is affected in amount and direction by the cycling conditions used, both lengthening and shortening having been observed at Los Alamos. The subject has been reviewed in detail by Coffinberry and Waldron[15] and a mechanism proposed by which the observed effects might be produced.

MECHANICAL PROPERTIES

Apart from data on elastic moduli, information on the mechanical properties of plutonium has not yet been declassified. The most consistent series of values for the elastic constants, determined by Laquer[15] using a pulse technique, is shown in Table 6. The value for Young's modulus receives some confirmation from the work of A. E. Kay and B. W. Lowthian,[16] who derived a value of 9.9×10^{11} dyne/cm^2 from compression tests at room temperature; the value for Poisson's ratio determined at the same time was 0.4. The compressibility figures are in good agreement with those determined by P. W. Bridgeman (unpublished data reported by Coffinberry[15]). Konobeevsky[12] reports a value for the micro-hardness of α-plutonium as 223-250 kg/mm^2.

COMPATIBILITY

Gases

Plutonium appears to be more reactive chemically than uranium. It oxidizes slowly in dry air at 50°C (Fig. 3) forming an oxide film, PuO which appears to be protective.[16] In moist air, the rate of attack is much more rapid, and non-protective oxide layers (PuO_2) are formed. It may be expected that plutonium will oxidize more rapidly than uranium at corresponding temperatures, and that ignition of the metal in air will occur at temperatures in the region of 300°C. Freshly prepared plutonium powder and turnings may be pyrophoric. The compounds PuO, Pu_2O_3 and PuO_2 have been reported, and all these may be found simultaneously on oxidized metal.

No data are available on oxidation rates in CO_2, but comparison of thermodynamic data suggests that CO_2 will be reduced to CO or C and the carbon deposit may react to form PuC if excess metal is present.

The metal reacts only very slowly with pure nitrogen at 250°C and prolonged heating of milligram quantities at 800-1,000°C did not bring about complete conversion to the nitride.[20] The product of the reaction is PuN and no other compounds are known. Plutonium nitride is quite reactive and is very easily decomposed by moisture or on heating in air.

Plutonium reacts rapidly with hydrogen at 200°C and at an appreciable rate at 24-50°C.[21] A hydride of approximate formula PuH_3 is normally formed, but it is likely that the reaction proceeds in two stages:

$$Pu+H_2\rightarrow PuH_2 \qquad H_{298}=-32.5 \text{ kcal/mole}$$
$$PuH_2+\tfrac{1}{2}H_2\rightarrow PuH_3 \qquad H_{298}=-(>9.5) \text{ kcal/mole.}$$

The two hydrides normally exist in solid solution with one another and the resulting phase has a reactivity similar to that of Pu metal.[22] It oxidizes slowly in air below 100°C and reacts smoothly with water and acids; it may be converted to PuN by heating in nitrogen at 230°C or to the carbide at 800°C. In consequence it is frequently used as the starting point for the preparation of other plutonium compounds. The dissociation pressure of the hydride mixture is low at temperatures up to 500°C and the compound is stable at 1,000°C under one atmosphere pressure of hydrogen.

On heating the metal in ammonia gas at temperatures of 800-1,000°C a mixture of products including PuN and PuO_2 is usually obtained.[20] The metal is vigorously attacked by most of the remaining inorganic gases, e.g. the halogens, halogen acid gases and sulphur compounds. The heats of formation of a number of common plutonium compounds are shown in Table 7.

Liquid Metals

No data have been published on the compatibility of plutonium with the alkali metals, but lithium has been used in the reduction of plutonium compounds and formation

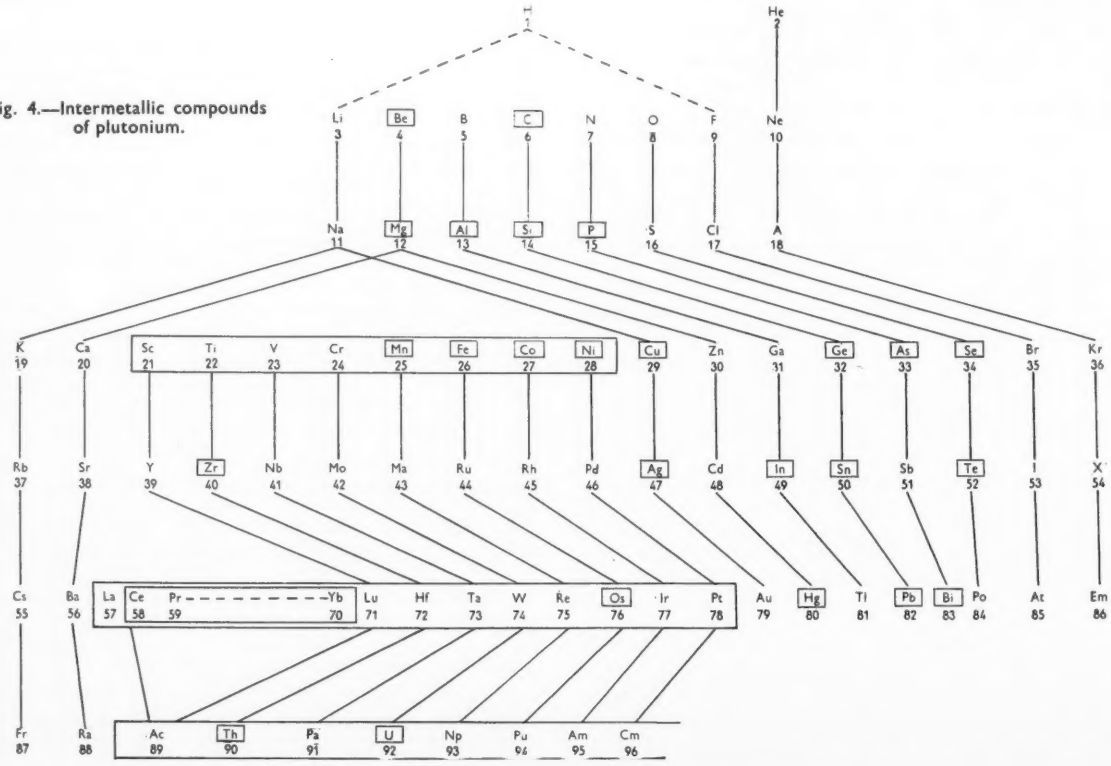


Fig. 4.—Intermetallic compounds of plutonium.

of solutions or intermetallic compounds has not been observed. It is quite certain, however, that in a circulating system plutonium will reduce any oxide of sodium, potassium, etc., present in the system, and severe corrosion of the metal may occur by this mechanism unless the highest standards of purification are maintained.

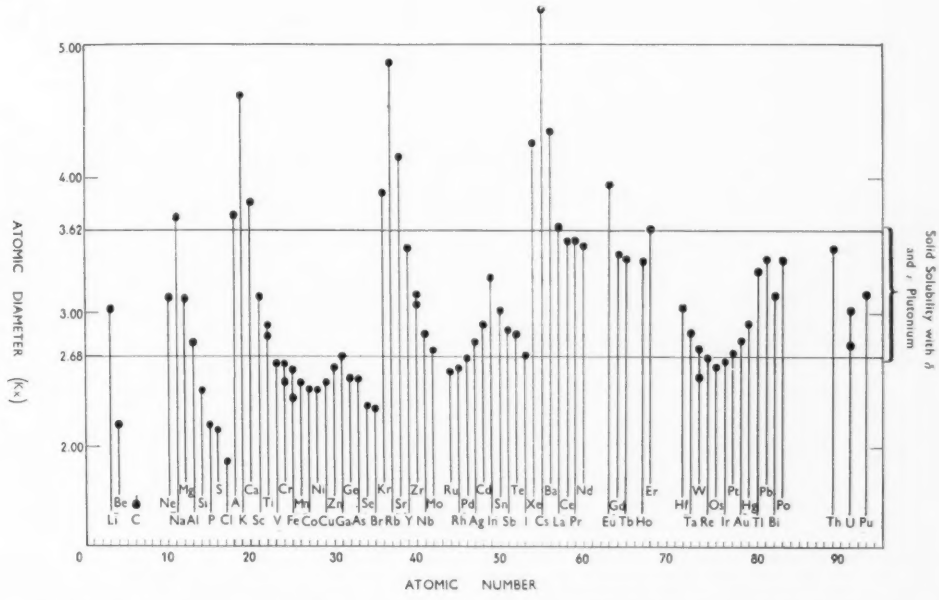

5.00
4.00
3.62
3.00
2.68
2.00
ATOMIC DIAMETER (Kx)
Solid Solubility with δ and ε Plutonium
Li Be B C
Ne Na Mg Al Si P S Cl A K Ca Sc Ti V Cr Mn Fe Ni Co Cu Zn Ga Ge As Se Br Kr Rb Sr Y Zr Nb Mo Ru Rh Pd Ag Cd In Sn Sb Te I Xe Cs Ba La Ce Pr Nd Eu Gd Tb Ho Er Ta Hf W Re Os Ir Pt Au Hg Tl Pb Bi Po Th U Pu
0 10 20 30 40 50 60 70 80 90
ATOMIC NUMBER

Fig. 5.—Elements capable of forming extensive solid solutions with plutonium.

It is known that plutonium forms compounds with the low melting point metals Hg, Sn, Pb, Bi, Mg and Al, and it may be inferred from a study of Fig. 4 that compounds will also be formed with gallium, antimony, thallium, zinc and cadmium. Thus, apart from the pure alkali metals, and the alkaline earth metals, no liquid metals are likely to be compatible with plutonium.

High Melting Point Metals and Compounds

Metals. It can be seen from Fig. 4 that the pattern of intermetallic compound formation followed by plutonium is remarkably similar to that of uranium. Thus compounds are likely to be formed with all the metals in the b- subgroups of the Periodic Table, with beryllium and with the 3d transition elements Mn to Ni. Moreover the types of compounds formed by plutonium bear strong resemblances to equivalent uranium compounds in composition and structure. The similarity in alloying behaviour is further strengthened by the formation of simple eutectic systems with V and Cr in each case. Any differences between the behaviour of the two heavy metals, e.g. the appearance of compounds in the Pu-Mg, Pu-Th systems, which are not present in the corresponding uranium systems, suggest a stronger tendency to compound formation by plutonium. Thus it may be assumed that intermetallic compounds will be formed with all the elements in the sub group VIIb and Group VIII, and, as exemplified by the Pu-Os system, eutectics may be formed at temperatures below the melting point of plutonium.

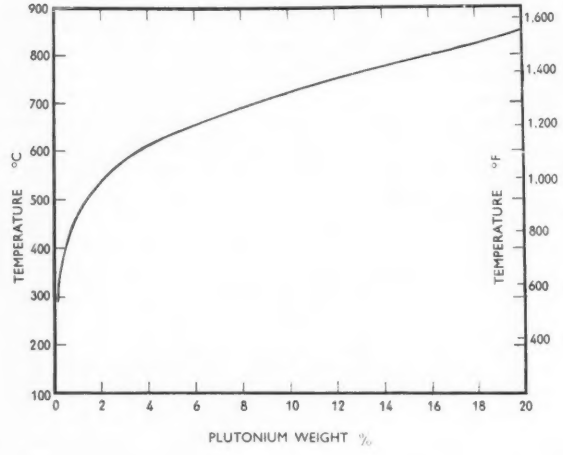
Thus as in the case of uranium, the search for compatible metals is narrowed down to the heavier elements in sub groups IVa to VIa. Application of the Hume-Rothery 15% rule (Fig. 5) indicates that size factor considerations favour extensive solid solubility between δ or ε plutonium and Zr, Hf, Ta, Nb, Ti, W and Mo among metals in these groups, the difference in atomic diameter increasing progressively from Zr to Mo. (The atomic diameters in Fig. 5 are corrected where necessary to a co-ordination number 8.) Hence in the strictest sense, these metals also are incompatible with plutonium. Assuming that the rates of diffusion of plutonium into these metals, and vice versa, are slow, it may be predicted that these metals will contain plutonium for relatively long periods at temperatures near its melting point. In the absence of relevant equilibrium diagrams and direct experimental evidence, it is not possible to state for what periods the refractory metals will contain liquid plutonium at high temperatures, but some guidance may again be sought from the behaviour of uranium. Investigations into the compatibility of uranium with other metals have shown that the rate of dissolution into liquid uranium was least for tungsten and tantalum, and reasons are given elsewhere[23] for supposing that these metals would be capable of containing plutonium or its alloys also for lengthy periods at high temperatures. Some confirmation for this view is given by the findings of Dawton and Wilkinson after evaporation tests on plutonium.[24]

Plutonium Alloys. Plutonium is such a concentrated form of fissile material that it must be diluted for use in power-producing reactors. In addition it is ill-adapted by reason of its chemical reactivity, structural complexity and physical properties for fabrication or use in the pure state. Consequently intensive research has been carried out on the possibility of alloying to eliminate these defects, and some data on alloy systems are now becoming available. Seven complete equilibrium diagrams have been published by the U.S.S.R.[12] and features of the Pu-Cr system indicated. Diagrams of the Pu-Th[25] and Pu-Fe[26] systems have recently been released from A.E.R.E., and the Pu-Zr diagram is shortly to be published. The solubility of plutonium in bismuth has been shown in the U.S.A.E.C. Reactor Handbook.[27] The diagrams for these systems are shown in Figs. 6-15. Additional information on the phases formed in these and other systems is given in Table 8.

Refractory Materials. Because of its extreme reactivity, the melting and casting of plutonium present some particularly awkward problems. Graphite reacts with plutonium

Fig. 6.—See back of Data Sheet.

Fig. 7.—(Below) Solubility of plutonium in molten bismuth.



at 800°C forming the carbide PuC. Most of the refractory oxides, even those which appear to be thermodynamically more stable than plutonium oxide, e.g. BeO, are decomposed by plutonium with the formation of plutonium oxide and intermetallic compounds. Thus a refractory must be sought which is intrinsically more stable than the corresponding plutonium compound, and which does not include metal radicles likely to alloy with plutonium. Compounds based on calcium, e.g. the fluoride or oxide, or cerium, e.g. the sulphide, may well meet these requirements. As the volume of plutonium melted increases and the quantity of metal in contact with the crucible becomes relatively smaller, the refractory problem becomes somewhat simpler; even so, special materials require development if high purity material is to be handled on a large scale. Although tantalum or tungsten may provide a short-term solution, they are expensive and by no means easy to fabricate.

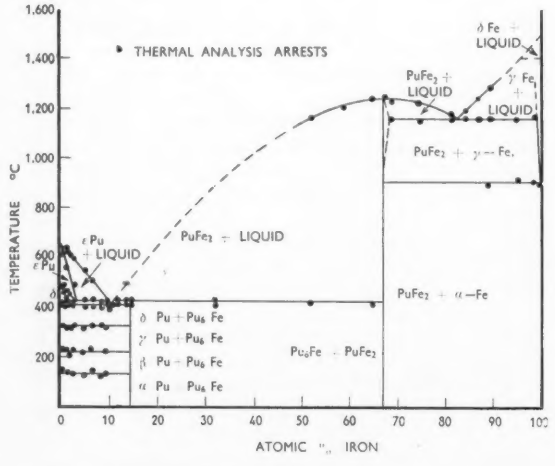


Fig. 9.—Equilibrium diagram for plutonium-iron system (Harwell data).

FABRICATION AND HANDLING

Fabrication

As is to be expected, the α form of plutonium is brittle and cannot easily be deformed except by hydraulic pressing. The δ-phase on the other hand is quite malleable and can be subjected to all the conventional forming operations such as extrusion, pressing and forging. The β and γ phases are also brittle but will probably respond to warm working. Although shaping of the metal is best carried out at elevated temperatures, the lowest practicable temperature should be used in order to minimize oxidation and avoid compatibility problems. The large volume changes on cooling may also be troublesome in causing distortion of products finished at high temperatures. Since plutonium does not shrink on solidification, however, smooth castings with flat tops may be obtained. The metal may be machined, cut and ground, provided due account is taken of the physical and metallurgical characteristics of the

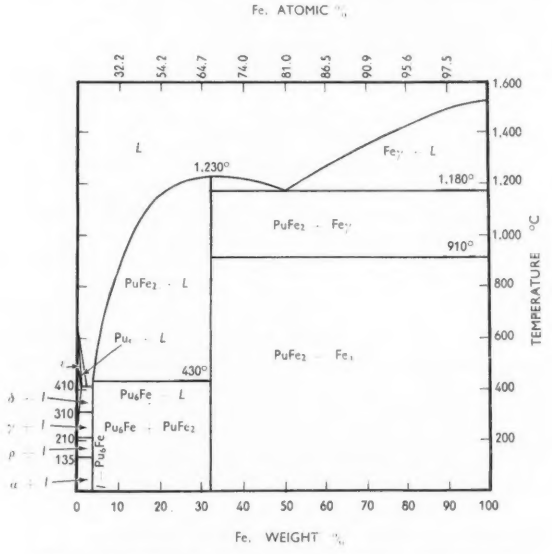


Fig. 8.—Equilibrium diagram for plutonium-iron system (U.S.S.R. data).

material. It must be emphasized that all shaping or machining operations carried out on the metal, particularly at elevated temperatures, involve severe hazards and must be carried out under the conditions prescribed in the next section.

Plutonium Handling Hazards

The hazards associated with the handling of plutonium are a consequence of two important nuclear properties of metal; it is fissile and it emits α-particles.

Because it is fissile material, plutonium has a critical mass, i.e. a mass at which the neutron chain reaction becomes just self sustaining. Beyond this point the radiation hazard due to γ rays and neutrons is vastly increased and the risk of explosion may be introduced. The critical mass for plutonium is small, of the order of a very few pounds, and every precaution must be taken to ensure that the quantity of plutonium metal in a given place at any one time is well below this limit. Thus before any plutonium handling facility begins to operate, it is mandatory that a clearance be obtained from experienced nuclear physicists that provisions for material storage, fabrication and movement are satisfactory from a criticality standpoint.

Nuclear Engineering

DATA SHEET

No. 3 Plutonium

PHYSICAL PROPERTIES

Symbol .. .. Pu
Atomic number 94
Mass number .. most abundant isotopes, 239, 240, 241
Source. Produced mainly by neutron capture by U^{238} in nuclear reactors.
Crystal structure .. .. Table 2
Phase transformation .. .. Table 3
Density and coefficient of expansion .. .. Table 4

Electrical resistivity .. ..
Specific heat .. .. .. c_p=0.032 cal/g, °C
c_p=7.65 cal/mole,
Heat of transformation .. .. $\alpha \rightarrow \beta$, ΔH=1.2 k
Vapour pressure .. .. mm Hg, in range 110
$\log_{10} P = (17{,}587 \pm 73)/T°K + 7.89$
Boiling point .. ..
Surface tension .. .. .. 100 dyne/cm (?)

TABLE 1
Nuclear Properties of the Isotopes of Plutonium

Nuclide	Half-life	Decay and energy, MeV	Principal method of formation	Thermal neutron data					
				σ_a	σ_f	σ_c	α	γ	
Pu^{232}	36 min	K, (98%) .. .. α (2%) 6.58	U^{235} (α, 7n) ..	—	—	—	—	—	
Pu^{234}	9 h	K, (96%) .. .. α (4%) 6.19	U^{233} (α, 3n) ..	—	—	—	—	—	
Pu^{235}	26 min	L, K .. .. α (.002%) 5.85	U^{233} (α, 2n) ..	—	—	—	—	—	
Pu^{236}	2.7 y	α (100%) 5.75 .. .. γ 0.04	U^{235} (α, 3n) ..	—	—	—	—	—	
Pu^{237}	~40 d	K, (no γ)	Np^{237} (d, 2n) ..	—	—	—	—	—	
Pu^{238}	90 y	α, 5.49, 5.45, 5.35 .. .. .. γ .044, .101, .149	Np^{238} (β^-) ..	—	—	—	—	—	
Pu^{239}	24,300 y	α, 5.15, 5.14, 5.10 .. .. .. γ .384, .124, .10, .039 and .05	Np^{239} (β^-) ..	1,022	731	291	.399	2,070	
Pu^{240}	6,600 y	α, 5.16, 5.12, 5.01 .. .. .. γ 0.05	Pu^{239} (n, γ) ..	350	4	346	86.5	.034	
Pu^{241}	13 y	β^- (99%) 0.02	Pu^{240} (n, γ) ..	1,336	971	365	.376	2.200	
Pu^{242}	9×10^5 y	α 4.90, 4.85	Pu^{241} (n, γ) ..	22.9	—	22.9	—		
Pu^{243}	5.0 h	β^- 0.56 .. .. γ 0.09, 0.12	Pu^{242} (n, γ) ..	100					

TABLE 2
Crystal Structure Data on Plutonium Phases

Phase	Crystal lattice	Unit cell dimensions A	Atoms per unit cell	Co-ordination	Distances of cl approach A
Alpha	Monoclinic (5)	At 21 a = 6.1835 ± .0005 b = 4.8244 ± .0005 c = 10.973 ± .001 β = 101.81° ± .02°	16	—	—
Beta	Structure unknown	—	—	—	—
Gamma	Face-centred orthorhombic (6)	At 235 °C a = 3.1587 ± .0004 b = 5.7682 ± .0004 c = 10.162 ± .002	8	10	4 Pu at 3.021, 2 Pu at 3.160, 4 Pu at 3.286, Average, 3.1
Delta	Face-centred cubic (7, 8, 9)	At 320 °C a = 4.6371 ± .0004	4	12	3.279 at 320 °C
Delta-prime ..	Face-centred tetragonal (7, 8, 9) (or B.C. tetragonal)	At 465 °C a = 4.701 c = 4.489 c/a = 0.955	4	—	—
Epsilon	Body-centred cubic (7, 8, 9)	At 490 °C a = 3.6361 ± .0004	2	8	3.150 at 500 °C

MECHANICAL PROPERTIES

Elastic moduli .. .. Ta
Hardness, αPu .. .. 223–250 kg/

COMPATIBILITY

(i) **Gases**
General compatibility with gases .. .. .. Tab
Heats of formation of some plutonium compounds .. Ta

(ii) **Liquid metals**
Plutonium is incompatible with all liquid metals apart from pure alkali and perhaps alkaline earth metals.

(iii) **Metals**
Alloy data .. .. Ta

.. .. .. Table 5
c_p=0.032 cal/g, °C at 20°C
c_p=7.65 cal/mole, °C
α → β, ΔH=1.2 kcal/mole
mm Hg, in range 1100–1500°C
17,587±73)/T°K+7.895±0.047
.. .. .. 3,500°K
100 dyne/cm (?) at 665°C

The Density and Coefficients o

Phase	Density, g/cm³	Temperature
Alpha	19.816±0.006*	25°C ..
Beta	17.77	150°C ..
Gamma	17.14±0.01*	235°C ..
Delta	15.92*	320°C ..
Delta prime	16.0*	477°C ..
Epsilon	16.48*	510°C ..
Liquid	(14) 16.50±.03	665°C ..

* Signifies X-ray value.

Resistivity

Phase	Resistivity, ρ×10⁶ (ohm/cm)	
	Smith (10)	Jette (8)
α	150 (25°C)	145 (25°C)
β	110 (200°C)	108 (150°C)
γ	110 (300°C)	107.5 (235°C)
δ	102 (400°C)	100 (370°C)
δ′	—	103 (475°C)
ε	120 (500°C)	111 (510°C)

ron data

α	γ	ϑ
—	—	—
—	—	—
—	—	—
—	—	—
—	—	—
—	—	—
.399	2.070	2.9
86.5	.034	3
.376	2.200	3
—		

TABLE 6
Elastic Properties of Alpha Plutonium at 30°C (Laquer, 15)

Property	Value	Pressure coeff. (×10⁻⁶/bar)	Tempera coeff. (×10⁻³
Young's modulus	9.93±0.03×10¹¹ dyne/cm² 14.40±0.04×10⁶ lb/in²	+18±1	−127±
Shear modulus ..	4.34±0.01×10¹¹ dyne/cm² 6.29±0.01×10⁶ lb/in²	+14±1	−145±
Poisson's ratio ..	0.15±0.01	+27±7	+138±
Compressibility ..	(2.14±0.02)×10⁻⁶/bar ..	−28±3	+69±

ation | Distances of closest approach A

	—
	—
	4 Pu at 3.021, 210°C 2 Pu at 3.160, 210°C 4 Pu at 3.286, 210°C Average, 3.155 3.279 at 320°C
	—
	3.150 at 500°C

TABLE 7
Heats of Formation of Some Plutonium Compounds

Compound	H_{298} kcal/mole
PuH_2	−32.5
PuH_3	−37
PuO	−135
Pu_2O_3	−387
PuO_2	−251
PuN	−95
PuC	−33
PuF_3	−375±1
PuF_4	−424±4
PuF_5	−453±5
$PuCl_3$	−230
$PuCl_4$	−330
$PuBr_3$	−199
PuI_3	−155
Pu_2S_3	−286

ES

.. Table 6
223–250 kg/mm²

.. Table 6a
nds.. Table 7

ls apart from the
ls.

.. Table 8

TABLE 3

Phase Transformation Temperatures in Plutonium Metal on Heating (7, 8)

Transformation	Temperature, C		ΔV, % $\Delta V = (V_2 - V_1)/V_1$
	Dilatometry	Thermal analysis	
$\alpha \rightarrow \beta$	122 ± 2	122	8.9
$\beta \rightarrow \gamma$	206 ± 3	203	2.4
$\gamma \rightarrow \delta$	319 ± 5	317	6.7
$\delta \rightarrow \delta'$	451 ± 4	453	−0.4
$\delta' \rightarrow \varepsilon$	480 ± 7	487	−3.0
ε to liquid		639.5 ± 2	

TABLE 4

Coefficients of Thermal Expansion of the Plutonium Phases

Temperature	Coefficient of linear expansion, 10^{-6}/ C	Temperature C
C	$(46.85 \pm 0.05) + (.0559 \pm .0004)t$	−186 to 100 (13)
C	33.86 ± 0.11	133 to 197 (13)
C	$\bar{\alpha}_a = -19.7 \pm 1.0$*	210 to 310
	$\bar{\alpha}_b = +39.5 \pm 0.6$	
	$\bar{\alpha}_c = 84.3 \pm 1.6$	
	$\bar{\alpha}_{polycryst} = 34.7 \pm 0.7$*	
C	−8.6 ± 0.3*	320 to 440
C	$\bar{\alpha}_a = 305 \pm 35$*	465 to 485
	$\bar{\alpha}_c = -659 \pm 67$	
	$\bar{\alpha}_{polycryst} = -16 \pm 28$	
C	36.5 ± 1.1	490 to 550
C	Volume coefficient = 50 ± 25 × 10^{-6}/ C	665

TABLE 5

Resistivity Data on Plutonium Phases

(ohm/cm)	Coefficient $(d\rho/dt).10^5$		
Ball et al (15)	Smith (8)	Jette (7)	Ball et al (15)
150 to 156	−29.7	−21	−22 to −40
115 to 119	0	−6	−4.8 to −17.7
114 to 118	0	−5	−3.6 to −8
108 to 112	+1.5	+7	+8 to +18
—	n	+45	0
124	0	−7	0

(Laquer, 15)

ure f. */bar)	Temperature coeff. (×10^{-5}/ C)
±1	−127 ± 8
±1	−145 ± 10
±7	+138 ± 71
±3	+68 ± 32

npounds

al/mole
5
±1
±4
±5
)
)
)
)

TABLE 6a

Compatibility of Plutonium Metal with Gases

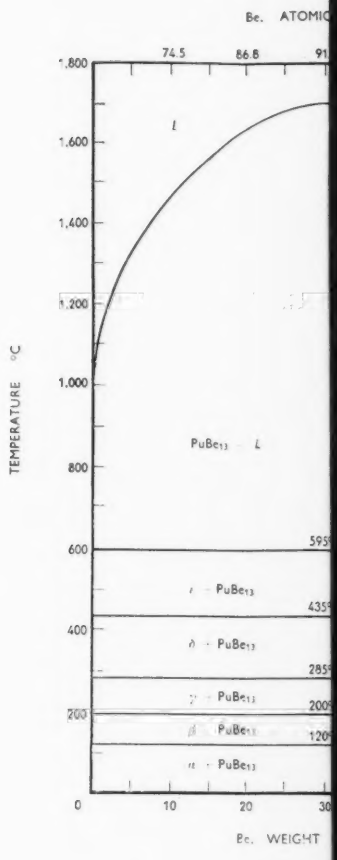
Gas	Product of reaction	Rate of reaction
H_2 ..	$PuH_{2.00}$ to $PuH_{3.00}$ ..	Slow at 25–50 C, very rapid at 200 C. Product of reaction normally has composition near PuH_3.
O_2 ..	PuO, Pu_2O_3, PuO_2 ..	Reaction with dry oxygen slow at room temperature when partly protective oxide films may be formed. Rate of reaction increases rapidly with temperature till ignition occurs. Presence of moisture accelerates oxidation.
CO_2 ..	PuO_2 (mainly) ..	Rapid at comparatively low temperatures. Plutonium reduces CO_2 to CO, when gas is present in excess, but reaction may go toward complete reduction to carbon, if metal present in excess.
IV_2 ..	PuN	Very slow at low temperatures, slow at temperatures in range 800–1,000 C.
F_2, Cl_2, Br_2, I	Appropriate halides in which valency of Pu may vary between 3 and 6	Strongly exothermic reaction with all halogen and halogen acid gases.

For Table 8, "Data on Plutonium Alloy Systems" see overleaf.

TABLE 8
Data on Plutonium Alloy Systems (15)

Element	Compounds formed	Structure	Unit cell dimensions (Å)	Density g/cm³	Additional i
Group I					
Hydrogen ..	$PuH_{2.0}$	f.c.c.	a = 5.539	10.40	See section on gas compatibility.
	$PuH_{3.0}$	Hex.	a = 3.78 ± .01 ..	9.61	
			c = 6.76 ± .01		
Lithium ..	—	—	—	—	Believed to be insoluble in plutoniu
Silver	$PuAg_3$	Hex.	a = 12.73	11.33	Probably a eutectic between silver
			c = 9.40		
Copper ..	PuCu (?)	—	—	—	Identified by X-ray and metallogr
	$PuCu_3$ (?) ..	—	—	—	uncertain.
	$PuCu_7$ (?) ..	—	—	—	
Group II					
Beryllium ..	$PuBe_{13}$	f.c.c.	a = 10.28	4.35	Equilibrium diagram, Fig. 6. Frequ
Magnesium ..	PuMg (?) ..	f.c.c.	a = 7.34 ± .01 ..		Exact composition uncertain. Eute
	$PuMg_2$ (?) ..	Hex.	a = 13.8 ± 0.1		
			c = 9.7 ± 0.1		
Mercury ..	$PuHg_2$	Hex.			Isostructural with UHg_2, UHg_4.
	$PuHg_4$	Pseudo b.c.c.			
Group III					
Aluminium ..	Pu_3Al	Tetr.	a = 4.499	11.33	$PuAl_2$, $PuAl_4$ isostructural with U
			c = 9.402		of Pu and Al in $PuAl_2$ observed.
	$PuAl_2$	f.c.c.	a = 7.84	8.06	UAl_3. PuAl may also exist.
	$PuAl_3$	Hex.	a = 6.10	6.67	and Al at 13 wt.% Pu, 640°C.
			c = 14.47		
	$PuAl_4$	Orth.	a = 4.41, b = 6.29 ..	6.02	
			c = 13.79		
Indium ..	Pu_3In	Cubic	a = 4.703	13.3	
Group IV					
Carbon ..	PuC	f.c.c.	a = 4.97	13.6	Isostructural with uranium carbides.
	Pu_2C_3	b.c.c.	a = 8.129	12.7	
Silicon ..	PuSi	Orth.	a = 5.727	10.15	Compounds Pu_5Si_3, Pu_3Si_2, and Pu_3Si
			b = 7.933		
			c = 3.847		
	α–$PuSi_2$	b.c.t.	a = 3.967	9.08	
			c = 13.72		
Germanium ..	Pu_3Ge	—	—	—	
	$PuGe_2$	b.c.t.	Ge rich, a = 4.102 ..	10.98	
	$PuGe_3$	Simple cubic ..	a = 4.223	10.07	
Tin	$PuSn_3$	s.c.	a = 4.630	9.96	
Lead	$PuPb_3$	f.c.c.	a = 4.808	12.86	Equilibrium diagram, Fig. 13.
Thorium ..	$PuTh_2$	Ortho.	a = 9.82	14.0	Equilibrium diagram, Fig. 14.
			b = 8.164		
			c = 6.681		
Zirconium ..	Pu_xZr	—	—	—	Williamson et al (unpublished work
	$(x > 3)$				in f.c.c. phase, 20–65 at.% Zr, Pu d
Group V					
Nitrogen ..	PuN	f.c.c.	a = 4.906		Isostructural with UN.
Phosphorus ..	PuP	f.c.c.	a = 5.664	9.87	Isostructural with UP.
Arsenic ..	PuAs	f.c.c.	a = 5.855	10.39	Isostructural with UAs.
Bismuth ..	PuBi	f.c.c.	a = 6.350	11.62	Solubility of Pu in Bi shown in Fig
					existence of $PuBi_2$.
Vanadium ..	—	—	—	—	Simple eutectic system (Fig. 15).
Group VI					
Oxygen ..	PuO	f.c.c.	a = 4.96	13.9	
	Pu_2O_3	Hex.	a = 3.841	11.47	
			c = 5.958		
	Pu_2O_3 to Pu_4O_7 ..	b.c.c.	a = 11.04 (Pu_2O_3 end)	10.2	
	PuO_2	f.c.c.	d = 5.396	11.46	
Tellurium ..	PuTe	f.c.c.	a = 6.183	10.33	
Chromium ..	—	—	—	—	Simple eutectic system with eutectic
					Pu (Cr content < .5 wt.%) M.Pt.
Uranium ..	γ Pu–U	Apparently s.c. ..	Pu_3U, a = 10.57 ..	17.15	Field of eta phase lies above that of
	2–70% U		c = 10.76		temperature within a narrower co
	Zeta–Pu	App. s.c. at room	PuU, a = 10.664 ..	18.95	
	25–74% U	temp.			
Group VII					
Manganese ..	$PuMn_2$	f.c.c.	Pu rich, a = 7.29 ..	11.95	Konobeevsky gives microhardness o
					Eutectic (2.3 wt.% Mn) 280–330.
					Compound, $PuMn_2$ 550–570.
					Eutectic (50 wt.% Mn) 760–820.
Group VIII					
Iron	Pu_6Fe	b.c.t.	a = 10.41	17.04	Microhardness, kg/mm² (Konobeevs
			c = 5.359		Pu_6Fe, 260; $PuFe_2$, 636.
	$PuFe_2$	f.c.c.	Pu rich, a = 7.19 ..	12.53	Eutectic 2.5 wt.% Fe, 230.
					Eutectic 50 wt.% Fe 473.
					Compound Pu_6Fe is plastic. Diagra
Cobalt ..	Pu_6Co	b.c.t.	a = 10.46	17.00	Pu_3Co(?) and $PuCo_3$ (?) also exist bu
			c = 5.33		
	Pu_3Co	Hex.	a = 7.902	14.0	
			c = 3.549		
	$PuCo_2$	f.c.c.	Pu rich, a = 7.081 ..	13.35	
	Pu_2Co_{17}	Hex.	a = 8.325	10.10	
			c = 8.104		
Nickel ..	$PuNi_2$	f.c.c.	Pu rich, a = 7.141 ..	13.1	Preliminary equilibrium diagram, Fig
			Ni rich, a = 7.115 ..		Compounds PuNi, $PuNi_3$ and $PuNi_4$
	$PuNi_3$	Hex.	a = 4.872	10.8	
			c = 3.980		
			to a = 4.861		
			c = 3.982		
	Pu_2Ni_{17}	Hex.	a = 8.29	10.3	
			c = 8.01		
Osmium ..	ζ Pu–Os	—	—	—	Equilibrium diagrams for region 0–6
	θ Pu–Os				has a homogeneity range from ab
	Pu_3Os				plastic properties and high densi
	$PuOs_2$	Hex.	a = 5.337	19.2	exists between 18.5 and 20 wt.
			c = 8.683		modifications, θ stable up to 620

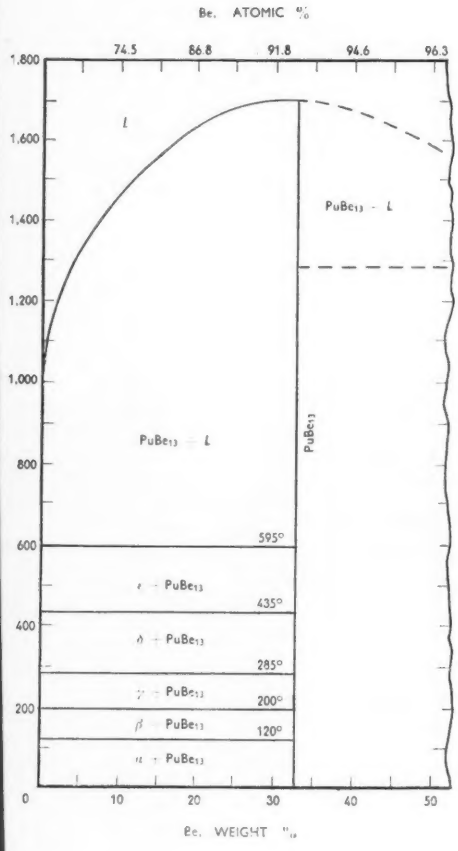
Additional information
mpatibility.
ble in plutonium. between silver and $PuAg_3$ at 10 wt.% Pu, 790 °C.
and metallographic evidence but composition
Fig. 6. Frequently used as neutron source certain. Eutectic at 15 at.% Pu, 552 °C.
Hg_3, UHg_4.
ctural with UAl_2, UAl_4 respectively. Solubility Al_2 observed. $PuAl_3$ structure differs from that of also exist. Eutectic reported between $PuAl_4$ Pu, 640 °C.
anium carbides.
U_3Si_2, and Pu_3Si_2, or β–$PuSi_2$ also thought to exist.
Fig. 13. Fig. 14.
published work) report extensive solubility of Zr 5 at.% Zr, Pu dissolves in α–Zr to approx. 13 at.%.
N. P. As. Bi shown in Fig. 7. Metallographic evidence for em (Fig. 15).
em with eutectic composition close to that of pure 5 wt.%) M.Pt. of eutectic, 615 °C. s above that of zeta phase which is stable at room n a narrower composition range.
microhardness of some Mn alloys (kg/mm²) % Mn) 280–330. 550–570. Mn) 760–820. Equilibrium diagram Fig. 10.
mm² (Konobeevsky). 86. e, 230. 473. plastic. Diagram, Figs. 8 and 9. (?) also exist but composition uncertain.
um diagram, Fig. 11. UNi_3 and UNi_4 also reported.
s for region 0–66.7 wt.% Os, Fig. 12. The phase ζ y range from about 2.7 to 4 wt.%, and shows good and high densities (18.3 g/cm³ at 3 wt.% Os). θ 8.5 and 20 wt.% Os. The phase exists in two table up to 620–625 °C, θ′ stable up to 680 °C.



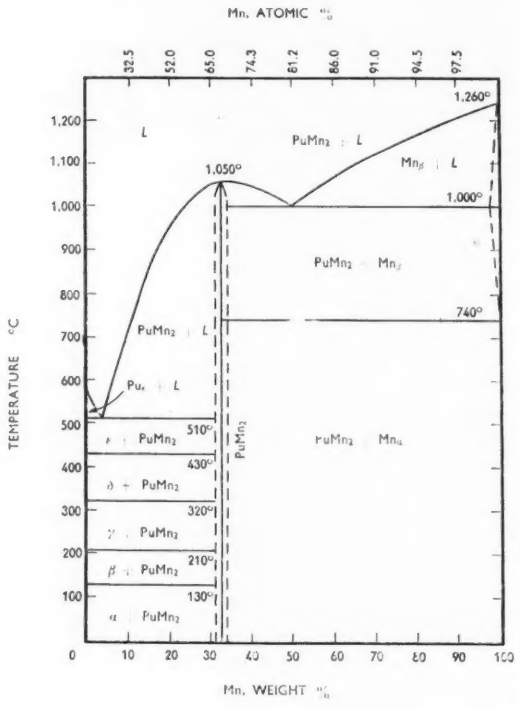
(Above) Fig. 6.—Equ
plutonium-

(Above, right) Fig. 11.
for plutoniu

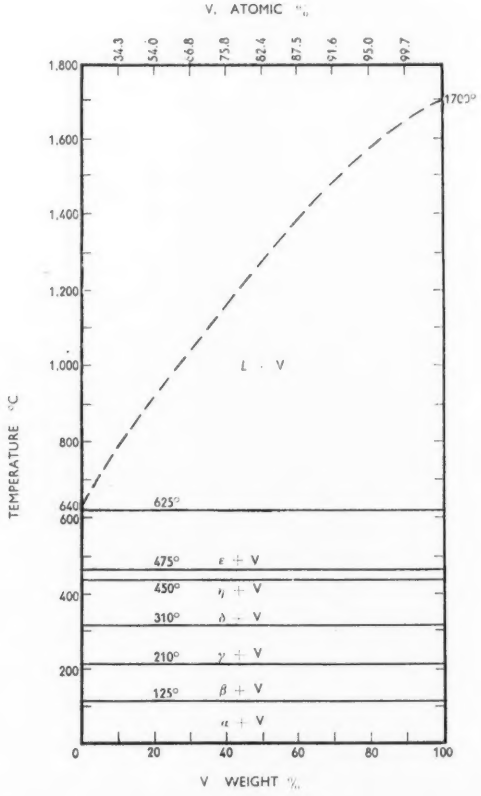
(Right) Fig. 15.—Equ
plutonium-



(Above) Fig. 6.—Equilibrium diagram for plutonium-beryllium.



(Above, right) Fig. 11.—Equilibrium diagram for plutonium-manganese.



(Right) Fig. 15.—Equilibrium diagram for plutonium-vanadium.

The problems created by the natural radioactivity of plutonium are encountered even when minute quantities of the metal are being handled. Plutonium is an alpha-particle emitter, the particles having an energy of 5.15 MeV and a range of 3.68 cm in air, 45 micron in body tissue. Certain plutonium isotopes also emit low energy gamma and high energy X radiation. In conjunction with light metals, e.g. beryllium, neutrons may also be produced. The biological half life of plutonium in the body is estimated to be about 100 years. Should plutonium enter the bloodstream, it rapidly becomes absorbed on the inner and outer surfaces of the bone, where it remains indefinitely, irradiating both body tissue and bone marrow and interfering with the production of white corpuscles. Ingested plutonium is not excessively dangerous, since it is quickly excreted, but metal is rapidly taken into the body through the lungs (10% of the amount inhaled being retained) or through cuts or abrasions of the skin.

The International Commission on Radiological Protection has fixed maximum permissible levels of plutonium exposure. They are: 2×10^{-12} μc/ml in air for continuous exposure, 6×10^{-12} μc/ml in air for exposures limited to 40 hours per week; 3×10^{-6} μc/ml in water; 0.04 μc (i.e. 0.6 μg) retained in the body. These tolerances would be

Fig. 11.—See back of Data Sheet.

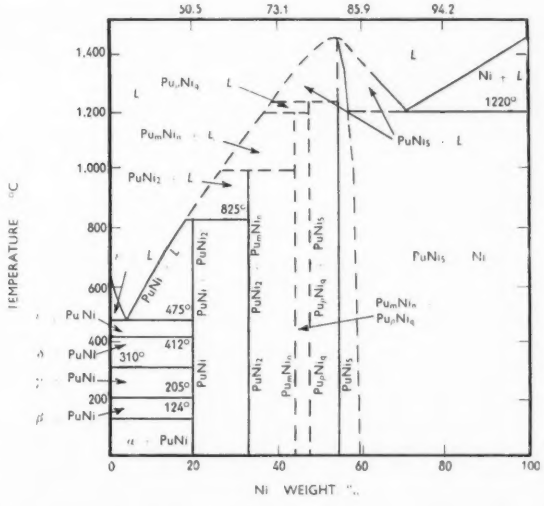


Fig. 12.—Equilibrium diagram for plutonium-nickel system.

sufficiently stringent in any circumstances but the extraordinary mobility of plutonium, due probably to the formation of microscopic particles of oxide, requires exceptional care to be taken in the construction and operation of plutonium handling equipment. All laboratories and plant require special attention to ventilation of the whole building, specially finished walls free from sharp corners and special drainage systems for radioactive waste. All processes involving plutonium solutions must be carried out in fume cupboards with a much greater airflow than that provided in normal laboratories. Operations inside the fume cupboard must be carried out with tongs since no unprotected skin should ever be exposed to plutonium-bearing materials. Work on any scale using an appreciable volume of plutonium, particularly when dry, must be carried out in hermetically sealed glove boxes.

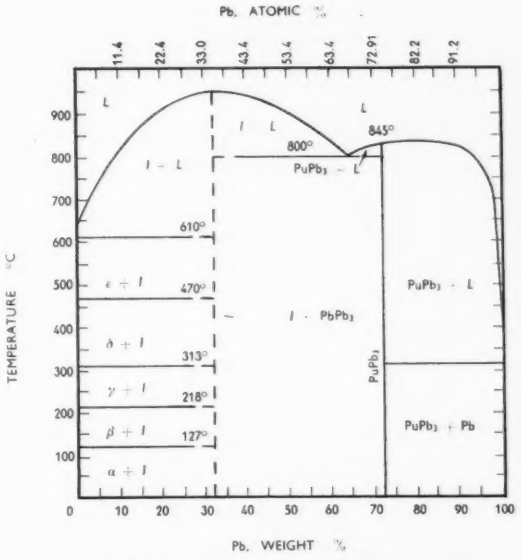


Fig. 10.—Equilibrium diagram for plutonium-lead system.

REACTOR CONDITIONS

It is highly improbable that pure plutonium will be used as a fuel rod in any type of reactor other than a zero energy fast fission system such as Zephyr. If the behaviour of uranium is any guide, attempts to produce heat by irradiation of plutonium will result in large changes in shape and dimensions, due in part to the effect of fission product accumulation, in part to irradiation induced structural changes, and in part to thermal cycling effects. In addition, the thermal conductivity of the metal is such that the surface temperature of the fuel must be kept low in order to avoid melting at the centre of the rod. In practice, the metal is likely to be alloyed with uranium or thorium, to promote breeding, at such concentrations that the irradiation behaviour of the alloy will be dominated by the characteristics of the fertile rather than the fissile

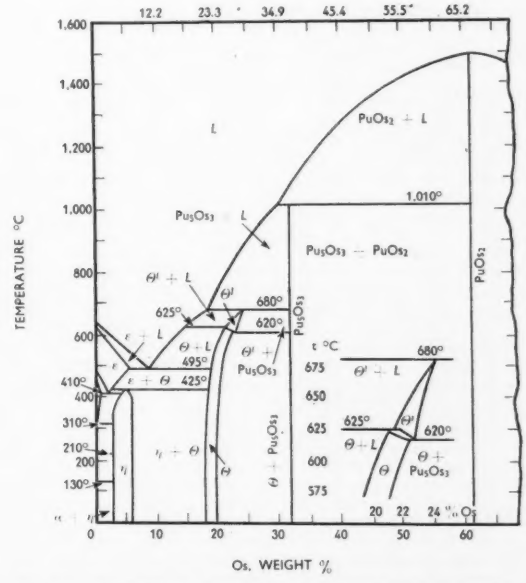


Fig. 13.—Equilibrium diagram for plutonium-osmium system.

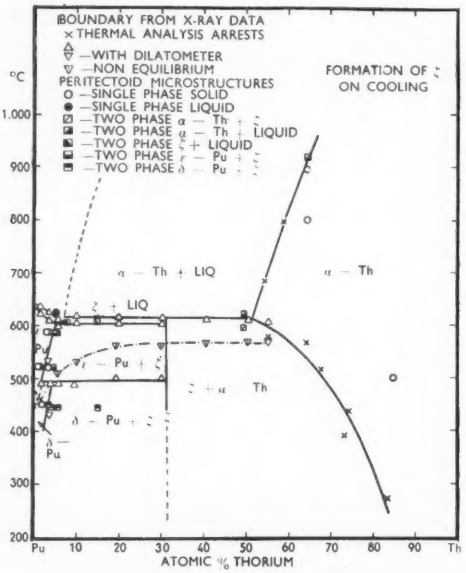


Fig. 14.—Equilibrium diagram for plutonium-thorium system.

Fig. 15.—See back of Data Sheet.

component. Alternatively, the metal may be alloyed with non-fissile metals such as zirconium, iron or nickel, or converted to the oxide or carbide to produce materials stable under irradiation. The solubility of plutonium in the liquid metals Bi, Sn, Pb, etc., and the low melting point alloys formed with other elements suggest the possibility of a liquid metal fuelled reactor which could eliminate irradiation damage problems, provided the compatibility obstacles can be surmounted.

Acknowledgments

The author is pleased to acknowledge the assistance given by colleagues in the Research, Weapons and Industrial Groups of the United Kingdom Atomic Energy Authority in making available information used in the article. Thanks are also due to Sir Leonard Owen, Managing Director, Industrial Group for permission to publish the paper, to Mr. L. Rotherham, Director, Research and Development, Mr. C. R. Tottle, Head of Laboratories Dounreay, and Dr. A. B. McIntosh, Head of Laboratories Culcheth, for their encouragement and helpful comments during its preparation. Acknowledgment is also made to the *Journal of the Institute of Metals* for permission to reproduce diagrams which are shortly to appear in that publication.

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Le Plutonium

Les applications, la rencontre et l'extraction du métal sont décrites dans l'article, et des données non classifiées se rapportant à l'emploi du matériau, y compris les propriétés physiques, les caractéristiques de fabrication, la compatibilité avec les autres matériaux, et les dangers de son maniement, y sont discutés. Des diagrammes d'équilibre sont représentés pour neuf systèmes binaires y compris le plutonium.

La métallurgie du métal soulève un nombre de questions intéressantes. Sa méthode de formation en association avec les matériaux intensément radio-actifs, et sa propre radio-activité inhérente exigent des techniques entièrement nouvelles de séparation et de fabrication. Cela a donné un essor au développement des procédés d'extraction avec solvants qui deviennent de plus en plus précieux dans d'autres applications. En tant que matériau fissile, le plutonium fait entrevoir la possibilité d'effectuer le " breeding " (réproduction) avec de facteurs de gain dépassant ceux des combustibles uranium, et la facilité avec laquelle il forme des alliages à point de fusion réduit pourra révolutionner la conception des réacteurs. Comme métal, il fait preuve de propriétés uniques dans le domaine de la métallurgie physique, et leur étude peut contribuer considérablement à la clarification de la théorie des métaux.

Plutonium

Anwendungen, Vorkommen und Gewinnung des Metalls werden beschrieben und verschiedene Daten über dessen Gebrauch, einschliesslich der physikalischen Eigenschaften, Verarbeitungsmerkmale, Verträglichkeit mit anderen Materialien und Gefahren der Handhabung besprochen. Es werden Zustandsdiagramme für 9 binäre Systeme mit Einschluss von Plutonium gezeigt.

Bei der Metallurgie des Metalls ergeben sich einige interessante Gesichtspunkte. So bedingen die Art des Entstehens in Verbindung mit stark radioaktiven Substanzen und die Eigenradioaktivität eine besondere Verfahrenstechnik bei Aufbereitung und Verarbeitung. Dies gab wiederum die Anregung zur Entwicklung von Gewinnungsverfahren mit Lösemitteln, die auch in anderer Richtung bedeutungsvoll sein können. Als Spaltmaterial verspricht Plutonium grosse Erfolge im Brutprozess mit Ausbeuten, die weit höher sind als die mit Uranbrennstoffen. Die Leichtigkeit, mit der Plutonium Legierungen mit niedrigem Schmelzpunkt bildet, wird unter Umständen eine Umwälzung im Reaktorbau hervorrufen. Als Metall zeigt Plutonium Eigenschaften, die in der physikalischen Metallurgie einzig dastehen. Deren genaues Studium wird in erheblichem Mass zur Klärung der Theorie der Metalle beitragen.

Plutonio

Se describen las aplicaciones, ocurrencia y extracción del metal, y se discuten datos no clasificados relacionados con el uso del material, incluyendo sus propiedades físicas, características de fabricación, compatibilidad con otros materiales y los peligros del manejo del mismo. Se ofrecen diagramas de equilibrio de los nueve sistemas binarios, incluyendo el plutonio.

La metalurgia del metal hace surgir una diversidad de características interesantes. Su modo de formación en asociación con material intensamente radioactivo, y su propia inherente radioactividad exigen técnicas enteramente nuevas de separación y de fabricación. Esto ha dado ímpetus a la evolución de procedimientos de extracción con solventes, los que están resultando de progresivo valor en otras aplicaciones. Como material hendible, el plutonio promete la posibilidad de criar con otros factores gananciales excediendo aquellos en los combustibles de uranio, y la facilidad con que forma aleaciones de bajo factor de derretimiento puede posiblemente revolucionar el diseño de reactores. Como metal, presenta propiedades únicas en su género en el campo de la metalurgia física y su estudio puede posiblemente contribuir grandemente a la clarificación de la teoría de metales.

REMOTE HANDLING

5. Handling Techniques

By R. A. G. WELSHER, A.M.I.Mech.E., A.M.I.Prod.E.
(*Remote Handling Group A.E.R.E. Harwell*

Previous articles in this series have discussed some of the requirements or alpha work and the use of glove boxes equipped with long rubber gauntlets for manipulation. Mention has also been made of some of the shielding systems used for beta-gamma and alpha-beta-gamma work. This article, the last of the series, deals with some of the techniques peculiar to the handling of these materials.

FOR beta-gamma work up to certain activity levels, distance can give protection and operations such as transfer from flasks to transporter coffins can often be carried out with long-handle tongs of relatively cheap construction. This type of tong is shown in Fig. 1, and was originally used by shopkeepers for the procurement of goods from high shelves, etc. Although the head is permanently formed at the angle shown it can be swivelled by hand

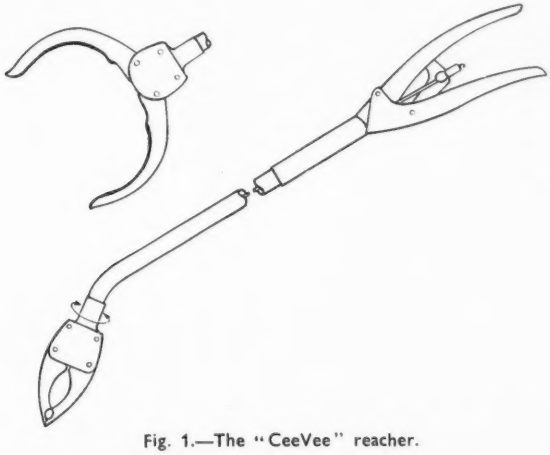


Fig. 1.—The "CeeVee" reacher.

about its axis to any desired rotational angle. Two sizes of jaw are available, and are known as "A" or "C" type with $2\frac{1}{2}$ in. or $4\frac{5}{8}$ in. opening respectively. The shaft range is from 2 ft 6 in. to 7 ft long. Where a shielding medium between the source and operator is imperative but where again, only very simple operations are required, a development of the above tong is made in an inverted "U" shape to allow it to be used "over the wall." Naturally the aforementioned have somewhat restricted use and detail manipulations require a more versatile tool. A system of remotely interchangeable-head tongs has been devised for this purpose and they work in conjunction with the sphere units mentioned in the article dealing with shielding.[1] Plain tubular shafts pass through the sphere having a pistol type handle with trigger at one end, and a head assembly with jaws at the other as shown in Fig. 2. The jaws or fingers on the head assembly can be fitted to suit the particular application and the head is retained by a spring mechanism which can be released by a small peg on the release plate shown. If a sequence of operations is contemplated, a series of heads with appropriate jaws can be parked behind the shielded area on the release plates and picked up by the operator, as required. Several

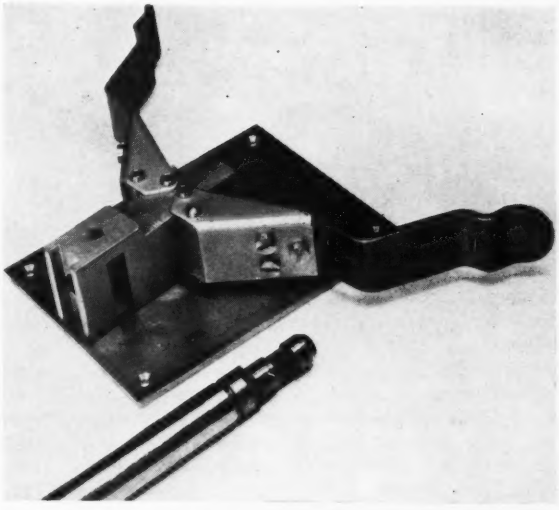


Fig. 2.—Tong shaft showing interchangeable head.

attachments are also available for these tongs which permit the remote cutting of wires, p.v.c. sheeting and tubing, besides the carrying out of such operations as sawing, filing, etc.[2]

Manipulative loads are naturally determined by the unsupported length of the tong shaft and can vary between 3 lb for a short tong to $\frac{1}{2}$ lb for the longer ones in the region of 5 ft.

One type of small low energy gamma cell is shown in Fig. 3 and is partially broken down for the purpose of clarity. The cell is constructed from steel-lead bricks and shows the relative positions of the tongs and viewing units. The framework is to support the small transporter trolley shown in the background. This trolley is operated from the outside by an endless wire and used for the transfer of items into the active area. It can also be used as a parking station for the changing of tong heads. Normally of course, the lead shielding would extend to the back of the frame to within trolley clearance distance.

Fig. 4 illustrates a special unit for the unscrewing of the small isotope can lids shown on the platform. The shielding wall is constructed from standard lead bricks and supports the tube unit which contains a flexible shaft that can be rotated by the external hand knobs. By means of a second concentric flexible shaft, small jaws can be made to open by pressing the smaller external knob and these grip the

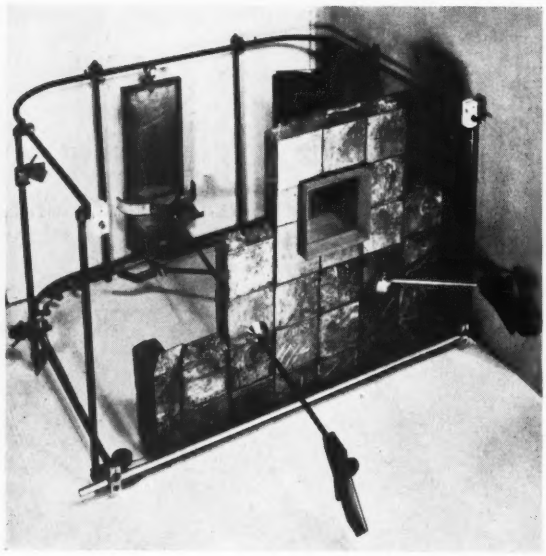


Fig. 3.—Small low-energy gamma cell partly broken down to show the construction. At the rear is a transporter trolley.

rectangular protrusion on the can lid. The can is placed in an adaptation of a normal vice, by the simple tong shown, over which the tool can be positioned and unscrewing carried out.

An alternative unscrewing tool consists of a tube passing through a sphere unit which has an internal shaft rotatable by an external hand wheel or knob. The head is fixed to the inner end and contains a pair of bevel gears which transmits the drive through a right angle. To the lower end of the right-angle drive is attached an appropriate box-spanner type of fitment to suit the can lid.

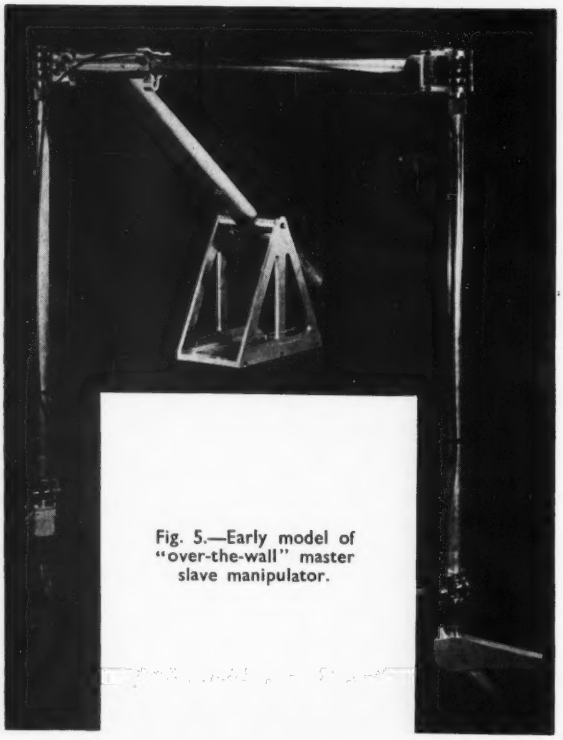


Fig. 5.—Early model of "over-the-wall" master slave manipulator.

Manipulators

An early attempt at a master slave manipulator in shown in Fig. 5, the vertical members being in the region of 3 ft long and 4 ft apart. It was intended for use as an " over-the-wall " tool and the master and slave ends had differential units which provided a wrist action. Vertical movement was obtained by swinging about the fixed support axis, whilst the sliding of the horizontal member through bearings in the T-shape member of the swinging tube provided the fore and aft movement.

Slotted steel tape working on toothed wheels was used to transmit the motions from the master to slave shafts. The slave end was adapted to take the standard interchangeable tong head as illustrated in Fig. 2, the push rod motion being transmitted into a " pull " and operated by a flexible Bowden type cable and cover.

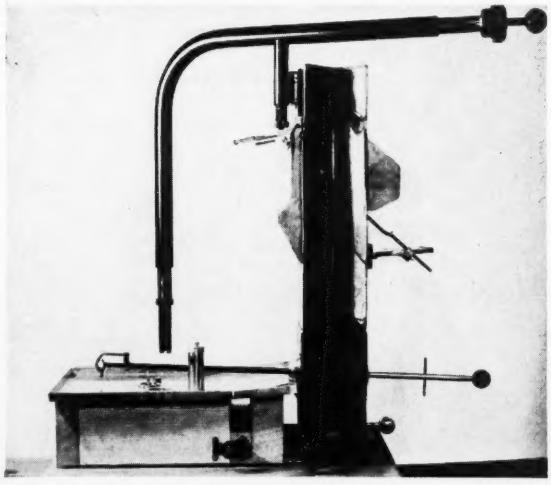


Fig. 4.—Special unit developed for unscrewing the lids of isotope cans.

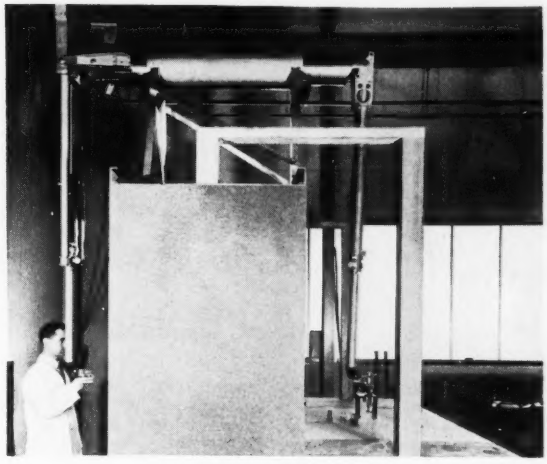
The machine was designed for relatively light work and had a lifting capacity of up to 2 lb, however, other than having a greater range, it had little advantage over a standard tong-sphere unit and was less robust, besides being more expensive.

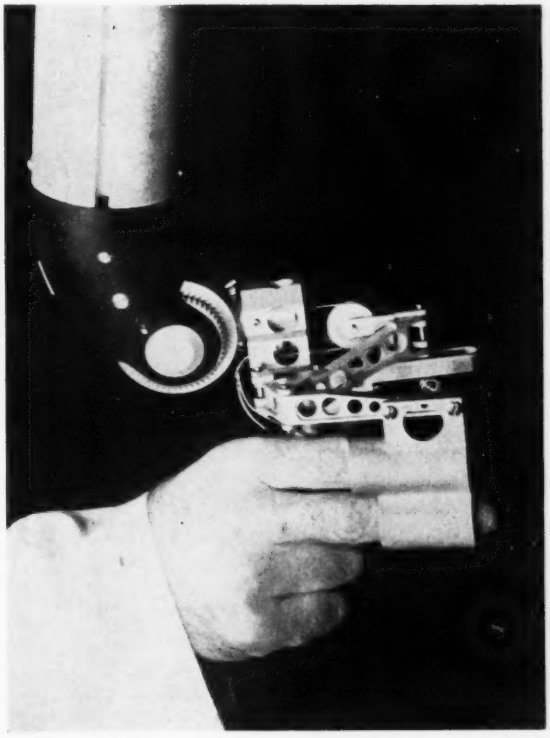
A pair of similar machines but of larger and more robust construction was manufactured in late 1953 and has since been used quite successfully in conjunction with a concrete cell with 3 ft thick walls.[2] The vertical members were approx. 4 ft 6 in long and 6 ft apart, and contained concentric tubes for the various motions. Transmission of the motions between these tubes was by Bowden cable working on grooved pulleys. The latter was found to be much cheaper than the slotted tape and quite as efficient. The load capacity was in the region of 3 to 4 lb.

Since the early part of this year the American type Argonne No. 8 master slave manipulator has been available in the U.K. and several are now in use (Figs. 6 and 7). Only relatively short operating times have been possible and hence operating experience is rather restricted. The transmission of movement from the master to slave end is by steel tapes in the region of $\frac{3}{16}$ in x 0.006 in and 0.093-in flexible wire; the only powered movement is an actuator which elevates the slave arm. The latter assists entry

Fig. 7.—(Right) Detail view of the master end of the unit shown in Fig. 6.

Fig. 6.—(Below) The "Argonne" type master slave unit.

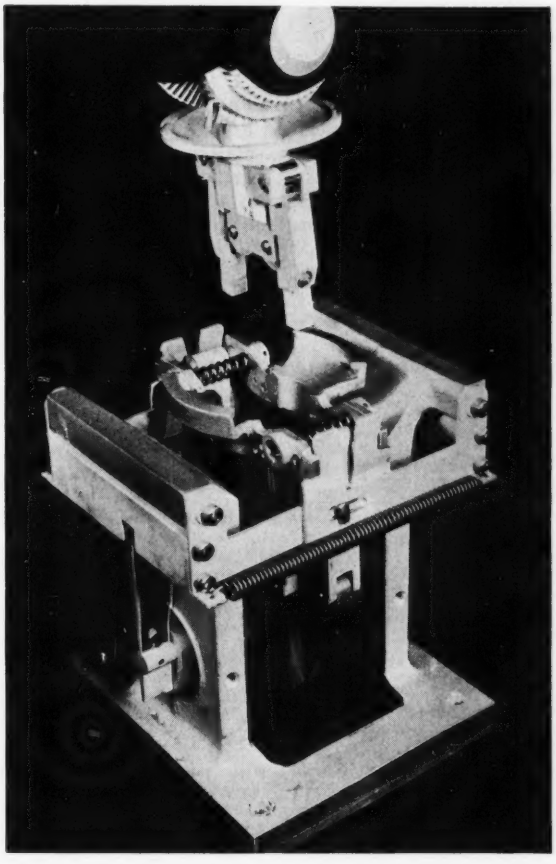




through the ports in the cells and also extends the working range.

These machines can be obtained for use with cells of almost any thickness but usually, the actual wall thickness is limited by the maximum distance for comfortable viewing.[3] To protect the slave end from gross contamination plastic sleeves are often fitted. Further work is in hand to develop an external bag changing technique and complete hermetic sealing of the slave end. Jaws can be changed remotely by use of a jaw change station Fig. 8, a separate station being necessary for each jaw.

Fig. 8.—Jaw change station.



Alpha-Beta-Gamma

Tongs used in conjunction with lead-shielded airtight boxes have been the main tools for the α-β-γ work.[4] Gaiters manufactured from .008 in laminated (2 x .004) p.v.c. give an airtight but flexible seal between the box and the tong shaft. The tongs are similar to those previously described and use the interchangeable head system of Fig 2. However, the tong end consists of an adaptor on which the gaiter terminates and this includes an airtight diaphragm mechanism for operating the tong heads. The tong tube is attached to this adaptor by way of a bayonet fitting arrangement which allows the tong shaft to be withdrawn for gaiter change or box withdrawal.

Transfer Systems

To combat the dust hazard associated with alpha-beta-gamma transfer operations an adaptation of the p.v.c. bag transfer system is employed.[4] These are shown in Figs. 9 and 10 and are almost self explanatory. A certain amount of technique is necessary to change the p.v.c. bag but even more is required to manœuvre it into a suitable position for sealing and cutting through.

Boxes and Cells

The positioning of the tong head change stations should be studied carefully to ensure maximum box coverage and convenience. In many cases, simple mock-ups of tong positions and equipment can be invaluable in the assessment of optimum positioning. It is imperative that tong change stations be secured rigidly and not placed on easily deflected brackets. Avoid brightly plated tong heads, jaws

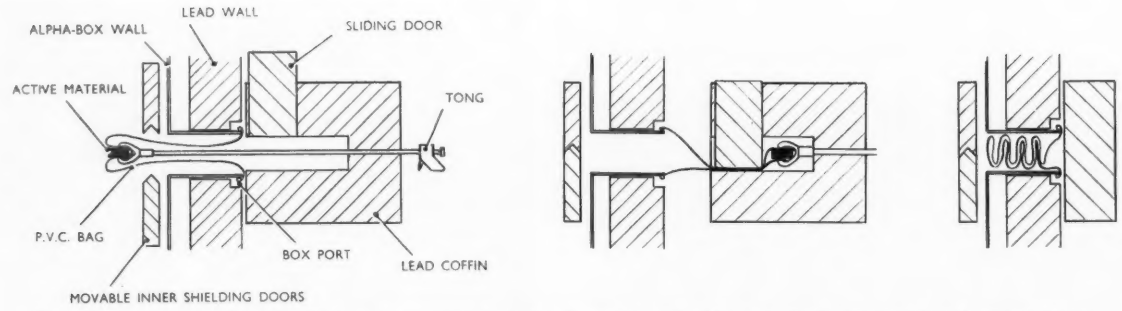


Fig. 9.—Three stages during removal of $\alpha\,\beta\,\gamma$-active material from cell. (On left) Lead coffin has been placed into position, inner and outer shielding doors removed and active material gripped through p.v.c. bag. (In centre) The material has been withdrawn (more slack s required than is illustrated) so that the bag can be sealed and cut between the coffin and the cell. (On right) Coffin has been removed and the shielding doors returned to place.

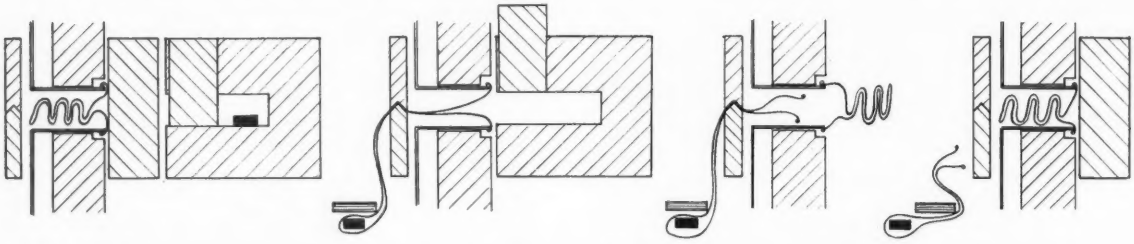


Fig. 10.—The reverse operation to Fig. 9; inserting active material in a cell. In the second diagram, the material has been manœuvred behind extra shielding to reduce radiation through access port so as to allow the coffin to be removed and a new p.v.c. bag with "O" ring to be placed in position and the first one slipped off (third diagram).

or equipment as these can give rise to really annoying back reflections. Naturally, all edges should be well radiused, where possible, to avoid damaging gaiters, tubing and rubber-lined tong jaws. Corrosion is another factor that can easily be overlooked, as rapid deterioration of springs and shafts in chemical boxes can occur, resin coatings, such as Araldite, can sometimes be used unless close sliding or running fits are required. Box atmospheres tend to encourage electrolytic reactions giving rise to stiffnesses in shafts and flexible control drives; cases of complete seizure are not unknown. This is also coupled with lubrication problems, and allowance for adequate maintenance must be provided.[5] It is of great advantage if electric motors etc., can be placed outside the cell or alternatively in a separate compartment of the inner box as this can greatly reduce decontamination times, and assist maintenance.

It is good practice to avoid all crevices and ledges which give rise to awkward decontamination conditions and very often, equipment and walls can be protected from gross contamination by the use of plastics coverings such as p.v.c. or polythene film.

The surface finish of boxes and cells can present many problems and, contrary to some beliefs, stainless steel is not necessarily the easiest surface to decontaminate. At one time, a base paint was used and then covered with a strippable lacquer the intention being to strip the latter off when it became active. This practice was, however, discontinued as the lacquer was continuously being rubbed off by accidental means. The trend at present is towards a hard gloss paint and amongst these the new epoxy paints show great promise.[2]

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La Protection des Systemes de Manutention

L'article final de la série consacrée à la Commande à distance traite des Pinces et Manipulateurs couramment employés. Pour les activités de faible importance, les pinces peuvent assurer un système de manipulation tout à fait suffisant, mais pour les opérations complètes à cellules à forte activité, les manipulateurs principaux et asservis sont nécessaires.

Les méthodes employées pour sceller les manipulateurs lors de l'opération avec des sources alpha-béta-gamma sont aussi l'objet de commentaires, et l'article se termine par des considérations d'ordre général sur la construction des boîtes et des cellules avec des conseils quant à la façon de les assembler.

Abschirmung von Betatigungs-Mechanismen

Der letzte Artikel der Serie über Fernbedienung befasst sich mit den gebräuchlichen Zangen und Manipulatoren. Für geringe Radioaktivitäten kann Handhabung mit Zangen vollkommen ausreichend sein, aber bei komplizierten Vorgängen mit stark radioaktiven Zellen sind Servo-Manipulatoren unentbehrlich.

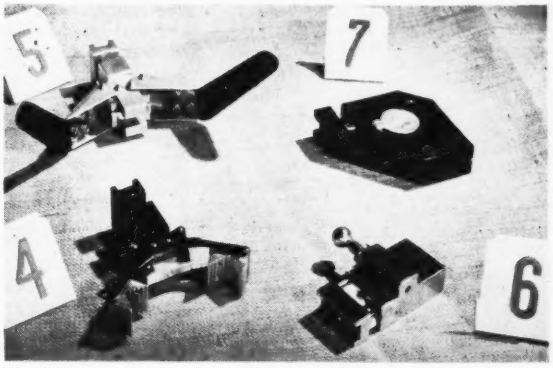
Weiterhin werden Verfahren für Abdichten der Manipulatoren bei Arbeiten mit Alpha-Beta-Strahlungsquellen erwähnt, und zum Schluss bringt der Artikel einige allgemeine Bemerkungen über den Bau von Zellen und Kästen und deren Anordnung.

Blindaje Protector de los Sistemas de Manipulacion

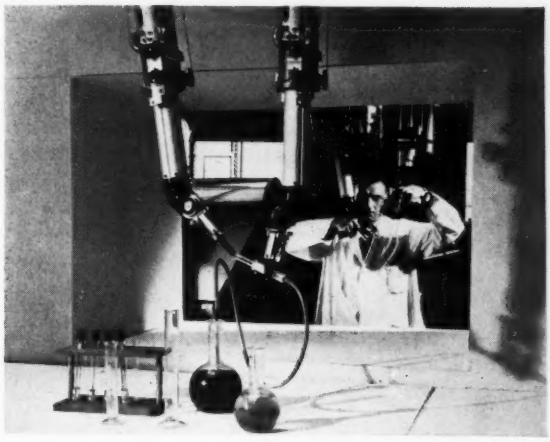
El artículo final en la serie sobre Manipulación a Distancia trata de las Tenazas y los Manipuladores que están empleándose actualmente. Para actividades bajas, las tenazas pueden ofrecer un sistema de manipulación del todo adecuado, pero las complejas operaciones con células altamente activas, son necesarios los Manipuladores "Master Slave" (Esclavo Maestro).

Se hacen comentarios sobre los métodos empleados para sellar los manipuladores cuando se están empleando fuentes alfa-beta-gama, y se concluye con algunos comentarios generales sobre el diseño de cajas y células y algunas ideas sobre el montaje de éstas.

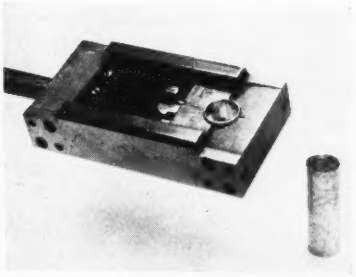
N.E.'s List of Suppliers of Remote Handling Gear



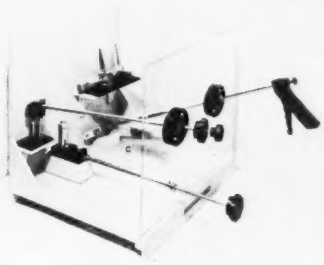
Group of interchangeable tong ends manufactured by Western Details, Ltd. 4, vice-grip jaws; 5, offset jaws; 6, mirror attachment block; 7, right-angle tong unit.



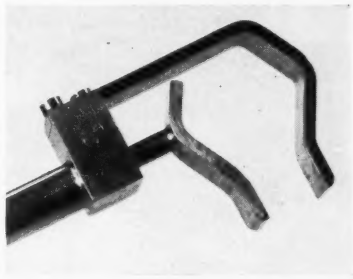
Master-slave mechanism built by Savage and Parsons, Ltd.



Can-opener head (Hambling Industries, Ltd.).



Tong units built by H. L. Instruments, Ltd. and sold by General Radiological, Ltd.



Duck-head tongs by Hambling Industries, Ltd.

SHIELDING MATERIALS

Appleton and Howard, Ltd., Salisbury Street, St. Helens, Lancs.
Associated Lead Manufacturers, Ltd., Ibex House, Minories, E.C.3.
Blundell and Crompton, Ltd., West India Dock Road, E.14.
British Lead Mills, Ltd., Byron House, 7 St. James's Street, S.W.1.
Cairns and Co., Ltd. (barytes aggregates), 14-15 Coleman Street, E.C.2.
Chatwood-Milner, Ltd., 58 Holborn Viaduct, E.C.1; also Shrewsbury, Salop.
Ekco Electronics, Ltd., Ekco Works, Southend-on-Sea.
E.R.D. Engineering Co., Ltd., Ipswich Road, Trading Estate, Slough.
General Electric Co., Ltd. (heavy alloy spheres), Magnet House, Kingsway, W.C.2.
General Metal Utilisation Co., Ltd. (lead), 162 Edleston Road, Crewe, Cheshire.
General Radiological, Ltd., 15-18 Clipstone Street, Gt. Portland Street, London, W.1.
Graviner Manufacturing Co., Ltd., Graviner Works, Fareham Road, Gosport, Hants.
Grey and Marten, Ltd., City Lead Works, Southwark Bridge, S.E.1.
Haywards Steel Doors, Ltd. (doors), Luton, Beds.
Hull and Sons, Ltd., 174 London Road, Mitcham, Surrey.
International Meehanite Metal Co., Ltd., The, Meerion House, 4 Downside, Epsom, Surrey.
Isotope Developments, Ltd., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks.
Mills Packard Construction Co., Ltd., 32 Duke Street, Ipswich, Suffolk.
Newburgh Engineering Co., Ltd., Newburgh Works, Bradwell, nr. Sheffield.
Nuclear Engineering, Ltd., Greenwich Metal Works, S.E.7.
Optical Works, Ltd., 32a The Mall, Ealing, W.5.
Panax Equipment, Ltd., 173 London Road, Mitcham, Surrey.
Permali, Ltd., Bristol Road, Gloucester.
Pilkington Bros., Ltd., St. Helens, Lancs.
Randall, Ltd., P. E. (lead), 25 Floodgate Street, Birmingham, 5.
Rolls-Royce, Ltd., Derby.
Savage and Parsons, Ltd., Otters Pool, Watford By-pass, Herts.
Simon-Carves, Ltd., Cheadle Heath, Stockport, Cheshire.

DRY BOXES

BMB (Sales), Ltd., High Street, Crawley, Sussex.
Chatwood-Milner, Ltd., 58 Holborn Viaduct, E.C.1; also Shrewsbury, Salop.
Chichester Rubber Co., Ltd. (gauntlets), Roberta House, Chichester.
Fleetlands, Ltd., Gosport, Hants.
H. and E. Lintott, Ltd., Foundry Lane, Horsham, Sussex.
National Plastics, Ltd. (bungs and ports), Walthamstow Avenue, London, E.4.
Savage and Parsons, Ltd., Otters Pool, Watford By-pass, Herts.
Thermo Plastics, Ltd. (bungs and ports), Dunstable, Beds.
Towers and Co., Ltd., Wallingford Road, Industrial Estate, Uxbridge, Middx.; Victoria House, Widnes, Lancs.
Veedip, Ltd. (gauntlets), Trading Estate, Slough, Bucks.
Wilson and Partners, Ltd., Design House, The Mall, Ealing, W.5.
North-Jomac, Ltd. (gauntlets), Kirkman House, 54a Tottenham Court Road, London, W.1.
Vokes, Ltd. (filters), Guildford, Surrey.
J. W. and G. A. Yeowell, Ltd. (p.v.c. bags), 115 De Beauvoir Road, London, N.1.

REMOTE VIEWING

Barr and Stroud, Ltd. (telescopes), Caxton Street, Anniesland, Glasgow, W.3.
F. W. Berk and Co., Ltd. (optical zinc bromide), 1 New Oxford Street, London, W.C.1.
British Drug Houses, Ltd. (optical zinc bromide), Poole, Dorset.
Chance Brothers, Ltd., Glass Works, Smethwick, Birmingham.
J. Evans (Portsmouth), Ltd. (zinc bromide tanks), Marcyn Works, Goldsmith Avenue, Portsmouth.
Glass Developments, Ltd., Sudbourne Road, Brixton, S.W.2.
Laboratory Apparatus and Glass Blowing Co., 77 Grosvenor Street, Manchester, 1.
Marconi's Wireless Telegraph Co., Ltd. (industrial TV), Marconi House, Chelmsford.
Mendip Chemical Engineering, Ltd. (optical zinc bromide), Feltham Road, Ashford, Middx.
Optical Works, Ltd., 32a The Mall, Ealing, W.5.
Pilkington Brothers, Ltd., St. Helens, Lancs.
Pye, Ltd. (cells and industrial TV), 98 Highbury New Park, London, N.5.

MANIPULATORS (Remote Handling)

Bloctube Controls, Ltd., Bicester Road, Aylesbury.
Chatwood-Milner, Ltd., 58 Holborn Viaduct, E.C.1.
General Electric Co., Ltd., The, Magnet House, Kingsway, W.C.2.
General Radiological, Ltd., 18 New Cavendish Street, London, W.1.
Gordon and Co., Ltd., Dalston Gardens, Stanmore, Middx.
Hambling Industries, Ltd., Industrial Estate, Chichester, Sussex.
H.L. Instruments, Ltd., 43 Poole Road, Bournemouth.
Hobson, Ltd., Wolverhampton, Staffs.
Isotope Developments, Ltd., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks.
Martonair, Ltd., Parkshot, Richmond, Surrey.
Nuclear Engineering, Ltd., Greenwich Metal Works, S.E.7.
Pye, Ltd., Cambridge.
Savage and Parsons, Ltd., Otters Pool, Watford By-pass, Herts.
Solus-Schaoll, Ltd., 15-18 Clipstone Street, Gt. Portland Street, W.1.
Western Detail Manufacturers, Ltd., Western Works, Staple Hill, Bristol.

Production at Ettingshall

Nuclear Work of the John Thompson Companies

AN opportunity of seeing something of the expansion that has taken place in the works of John Thompson, Ltd., over the past few years, together with some of the particular products now under manufacture, was extended to leading representatives from associated companies and industries, the A.E.A., the C.E.A. and the technical Press. In addition, a reception and inspection tour was organized for local authority representatives and a wide variety of the company's customers to demonstrate the varying fields of activity in which the company is engaged. The John Thompson group at Ettingshall, Wolverhampton, comprises a number of heavy engineering concerns. Recently, the group's research has been co-ordinated into one building, with particular responsibility for investigating the numerous problems that have arisen as a result of the contract awarded to A.E.I.-John Thompson Nuclear Energy Co., Ltd., for the nuclear power station at Berkeley.

Berkeley

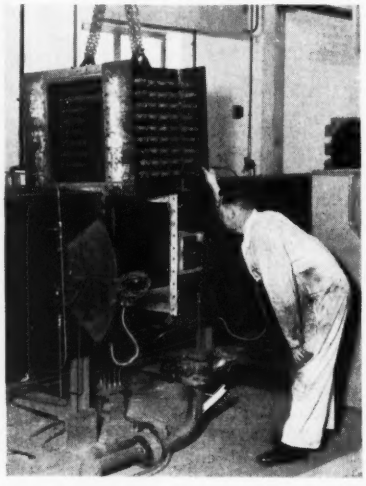
John Thompson's section of this power station includes pressure vessels, the heat exchangers, the charge and discharge gear, pipe work and ducting, in addition to numerous items of precision engineering. The experience of the company in the atomic energy field is already considerable as it has already been responsible, among other things, for the highly complex stainless-steel reactor vessel and the heat exchangers for the Dounreay fast reactor (see *Nuclear Engineering*, June, 1957).

The reactor vessel for Berkeley is one of the largest cylindrical steel fabrications undertaken in this country. The completed vessel will be 80 ft high and 50 ft diameter, comprising five centre cylindrical sections with a dome section at top and bottom. The steel thickness is 3 in.

Construction of the pressure vessel is largely a site operation using plates pressed in the works and transported by road. The petal plates for the domed ends are pressed whilst the cylindrical plates are roll formed. Special pendulum flame-planing equipment has been developed for edge preparation of the plates, so that no machining is necessary. Before transport to the site the sections and the domes are set up at the works and accuracy of the individual pressings checked. The final diameter is required to be within $^1/_{32}$ in. of the design figure.

The heat exchangers for the Berkeley station, of which there are eight per reactor, are shop-fabricated in five cylindrical sections and two domed ends. The specification for these was determined primarily by the maximum size transportable by road to the site, the final size being 70 ft high by 18 ft diameter fabricated from steel plate $1\frac{1}{8}$ in. thick.

The cylindrical sections of the vessel are fabricated from two steel plates cold-rolled in plate rolls which are capable of handling up to 6 in. thick plate (hot). A complex arrangement of thermal sleeves and tube entries is involved and the dome end sections are fitted with 5 in. diameter, 6 in. thick compensator rings for connection to the gas ducting. These are formed from 6 in. thick plate, rolled and seam-welded, the tube then being cut transversely to provide a number of rings.



Removing an experimental tube pack from the heat transfer test rig.

Welding

Welding is one of the major activities of the company and considerable effort is put into the development of automatic systems. In the heavy bending and welding shop a 4,000 amp gantry submerged arc-welding machine and a 2,000 amp low-lift boom machine are installed. An extension of the shop houses a new high-lift boom Unionmelt machine, capable of both inner and outer fusion welding runs on the seams of 18-ft shells. Welding of plates up to $3\frac{1}{2}$ in. thick can be carried out in a single inner and outer pass. The heat exchangers involve some 150 miles of welded joint.

A plain tube bank for Berkeley, presumably for the superheater section, was being exhibited; the evaporator and economizer sections are being constructed from Integron tubing. The company has

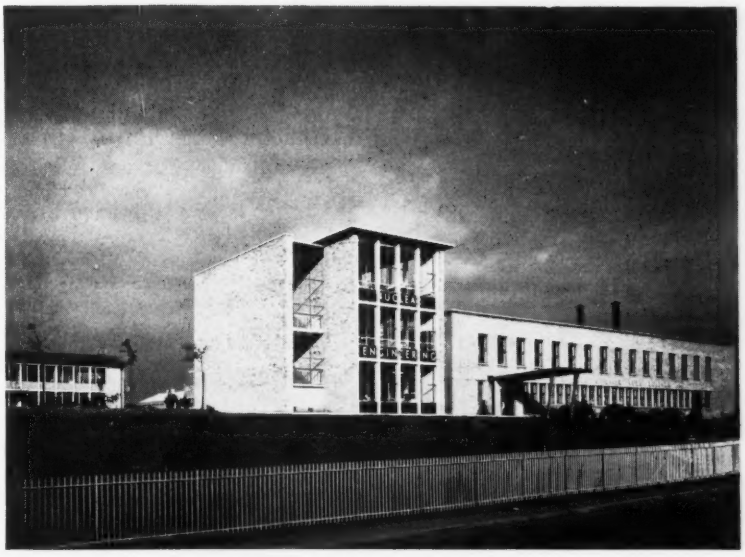
Section of the Berkeley pressure vessel temporarily erected in the works.

been experimenting with an extended surface heat exchanger tubing formed by expanding the water tube into evenly spaced square fins. Repeated thermal cycling and shock treatment has failed to decrease the heat transfer or damage the tubes, but at least for Berkeley Integron tubing will be employed.

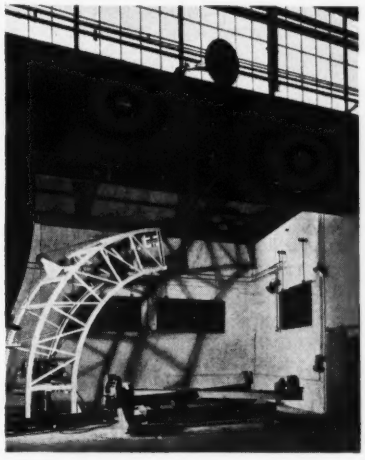
Amongst the detail equipment on view was a torque-compensated bellows joint manufactured by the company. A machine for forming the convolutions in the bellows part is in course of construction, so that complete assemblies can be made at Wolverhampton. In the same shop, the complex lead-filled shielding dome for the Merlin reactor was nearing completion.

Radiography is very much in evidence throughout the works, some six miles of film being involved annually. The large majority of welds in the power station will be radiographed and a wide variety of machines for this purpose have been installed and are available on site.

In previous issues, stainless-steel fabrication at the John Thompson works has been discussed and some of the later items destined for Dounreay were on show, including, for example, the zirconium hot traps which it has been deemed advisable to include in the primary circuit, in addition to the more conventional cold traps. The work of the stainless-steel section is, however, by no means limited to the atomic energy side and a considerable output for the chemical industry is handled.

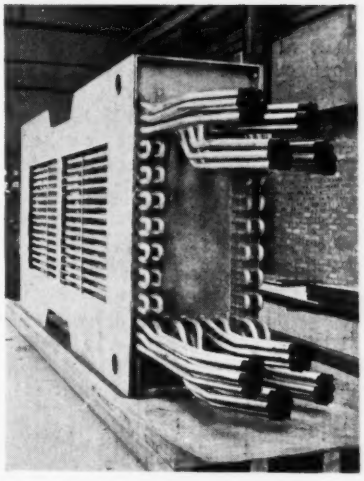


New headquarters of the Nuclear Engineering Department.



A new X-ray bay built on to the welding shop.

The centralized research group, apart from working on immediate problems concerned with the Berkeley station, is devoting considerable effort to the development and evaluation of heat transfer surfaces. In addition, the subject of reinforced pressure vessels is being investigated and it is likely that future tenders submitted by A.E.I.-John Thompson will include provision for a reactor vessel which is not a simple welded sphere. A cut-away section of the Dounreay sodium-to-water heat exchanger was on view in the department, showing the method of construction whereby the inner tube is wrapped with a spiral copper strip and then expanded into the outer tube, the bonding being made good by brazing. The space between the spirals is purged with nitrogen and monitored for leakage.



Plain (unfinned) heat exchanger tube pack as made up for transport to Berkeley.

Ring and dome end sections of the Berkeley heat exchangers.

The John Thompson Instruments Company is extending its activities and is now in a position to install complete instrumentation systems.

Value of the output from the group in 1956 was more than double that for 1952. Whilst the last year's figure included atomic energy work the major part stemmed from conventional power station plant. Berkeley, however, now represents a significant fraction of the output from the boiler shop.

ETR in Operation

A.E.C.'s New Testing Reactor at Idaho Falls

Said to be the most powerful testing reactor in the world, the U.S.A.E.C.'s Engineering Test Reactor went critical in September at the National Reactor Testing Station at Idaho Falls. The following description has been abstracted from papers presented at an industrial preview on October 2.

THE Engineering Test Reactor can be regarded as a logical development of MTR (Materials Testing Reactor) its near neighbour at Idaho Falls, which went critical in March, 1952. Pressure on the experimental facilities of the MTR has been such that an urgent need arose for a considerably more powerful unit with facilities for large components. With a heat output of 175 MW, an average neutron flux of 4×10^{14} n/cm^2-sec (thermal) and 1.5×10^{15} n/cm^2-sec (fast), the ETR is said to be the most powerful test reactor in the world.

It was decided, early in 1955 to locate the new reactor adjacent to the MTR to effect economies in operation. Contracts were placed with the Kaiser Engineers Division of the Henry J. Kaiser Co. and construction officially commenced on October 13, 1955, completion being achieved in less than two years, at a cost of $14 million, which, it is stated, does not include costs related to experiments.

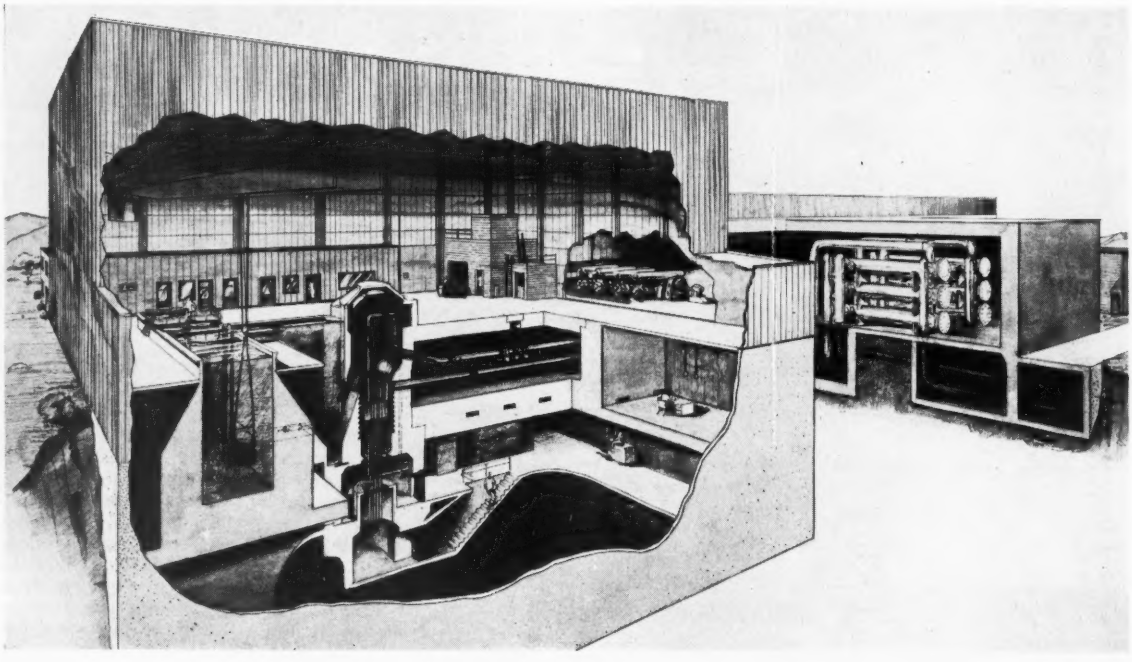
Other major contractors were the Phillips Petroleum Co., operators of the MTR, and General Electric who functioned as nuclear design sub-contractor.

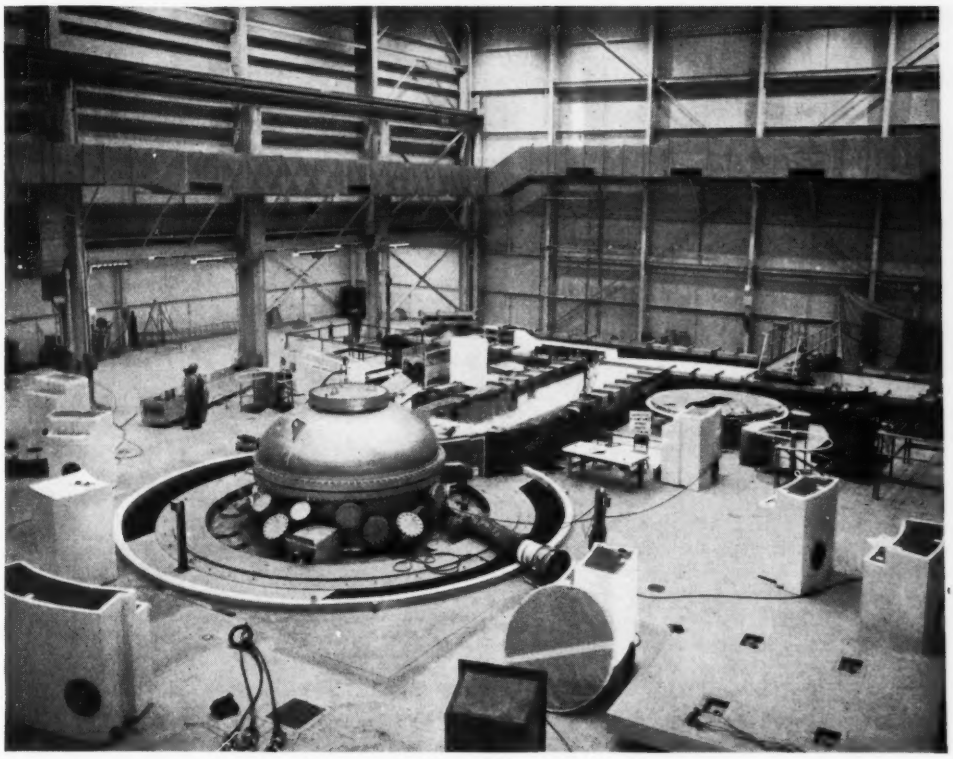
General Description

The ETR is fuelled with fully enriched uranium, with a reflector system consisting principally of beryllium, and uses light water as a moderator and coolant. Some idea of its general layout may be obtained from the accompanying cut-away illustration, from which it can be seen that the main building has several floor levels below the ground line. The reactor itself is contained in a pressure vessel at the approximate centre of the main building; the top of the vessel and the surrounding biological shielding being removable. On the floor below, to the right, is the tunnel for the main coolant pipes to and from the heat exchangers; immediately to the right of this can be seen the console floor where experimental instrumentation and control equipment is located. "Hot" equipment for the experimental loops, such as heat exchangers, pumps, etc., is housed in cubicles on the basement floor. At a still lower level is the control rod access room, containing the control rod drive mechanisms; this room has been made of unusual height to enable long sections of the control rod extensions to be withdrawn.

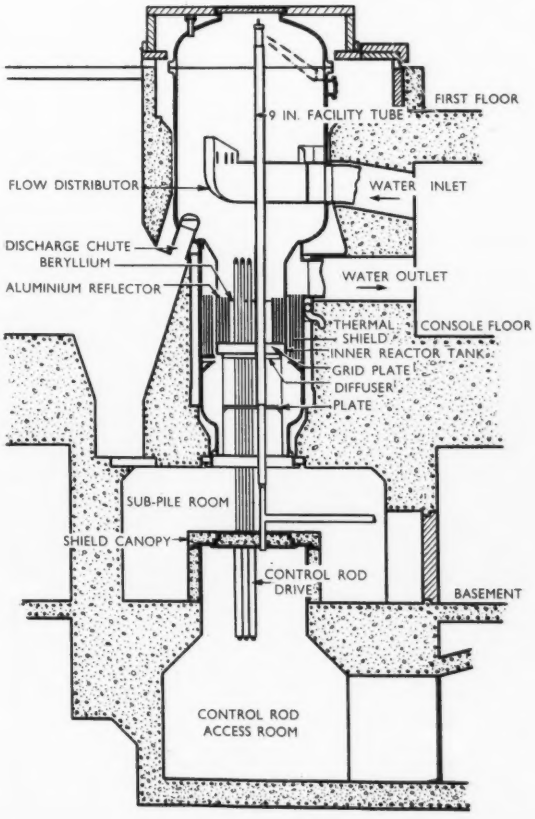
Between the control rod room and the bottom of the reactor vessel is what has been termed the "sub-pile"

Cut-away drawing of the ETR.





General view of the top of the reactor before erection of shielding.



Simplified cross-section of reactor.

room, which allows space for bends in piping from experiments in the reactor to be connected to the gear on the basement floor.

To the left of the illustration can be seen the so-called " canal " which is, actually, a deep pond, T-shaped in plan, into which leads a wide discharge chute from the reactor vessel, through which irradiated fuel elements, control rods, experimental equipment, etc., may be removed under water, and stored for subsequent removal.

The reactor building is 112 ft wide and 136 ft long, 65 ft high above ground level and 38 ft below. The canal is 60 ft by 35 ft and is 20 ft deep.

Pressure Vessel

The reactor pressure vessel, fabricated by O. G. Kelley and Co., of Boston, is approximately 36 ft high and, as will be seen from the section, has two diameters, the upper section being 12 ft and the lower 8 ft. It is constructed of stainless clad carbon steel and weighs some 75 tons as an empty shell.

In addition to the two 36 in. diameter nozzles for the main coolant inlet and outlet, and the discharge chute, there are many smaller nozzles in various locations for experimental loops; these are also in clad steel.

The vessel is supported at the point of transition from large to small diameter; this is accomplished by a number of flat plate supports welded to the vessel, sliding on flat plates resting on a bedplate anchored to the concrete, provision being made for preventing rotation or lateral movement. This gives a minimum of expansion movement at the coolant headers, but, of course, gives some relative movement between the bottom head of the vessel and the control rod mounting, for which compensation must be arranged.

The reactor core is supported on a grid support plate, located some distance below the coolant outlet. It is expected to sustain a total load, including fuel elements, experiments and force of the coolant circulation of some 200,000 lb and its design is correspondingly massive. Manufactured from stainless steel, it is 9 in. thick and is said to have required more than 600 penetrations during machining to its finished form and was, apparently, one of the most troublesome items to manufacture, requiring the pouring of two 45,000 lb ingots, and the forging of four discs before a satisfactory plate was produced. National Supply Co. of Torrance, California, produced the forgings, and the Modern Tool and Die Co., of Los Angeles carried out the precision machining, tolerances of 0.001 in. to 0.005 in. being specified. Alignment of this grid plate with the bottom head was required to be within 0.004 in. of their common axis.

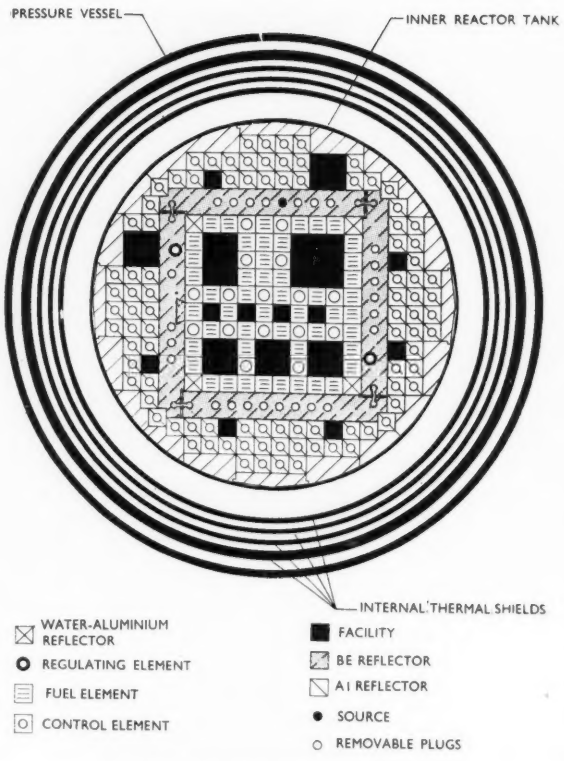
Core

A diagrammatic cross-section of the core is shown in the accompanying diagram. The fuel elements, each occupying a space of 3 in. x 3 in. are of the same type as used in the MTR, except that the active length is 3 ft instead of 2 ft and flat plates are used instead of curved. The total investment of uranium in the core varies, according to the experimental facilities present from 14-18 kg, the uranium being fully enriched, with an admixture of boron to act as a burnable poison and give greater uniformity to the reactivity during the working cycle, which is only 20 days in length.

Of the inner portion of the core, with its 100 3-in. squares, 49 are occupied by fuel elements and 31 squares are devoted to experimental facilities, varying from 3 in. x 3 in. to 9 in. x 9 in. Most of them being " through " holes so that loops can pass completely through the core. There are also 16 control rod positions.

Outside the core region is a slab-type reflector of beryllium which also contains experimental holes; the thickness of the reflector is 4½ in. This reflector section also contains the two regulating rods, of which one is a spare.

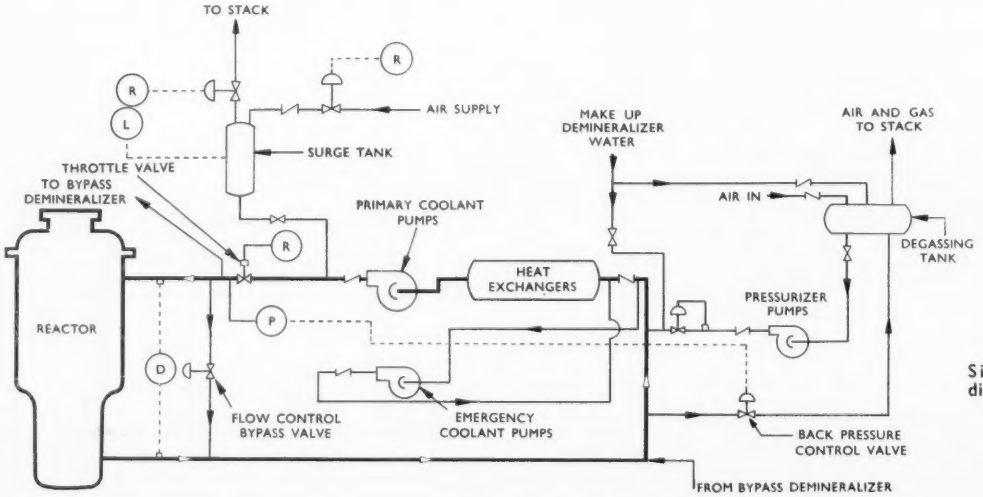
Outside the beryllium reflector is an aluminium reflector system, made up of separate pieces. Each piece contains an experimental hole in which samples may be placed; larger spaces can be created in this region by removal of a number of pieces. This region also contains four " through " holes similar to those in the core. This entire region is surrounded by an inner reactor tank; the space between this and the pressure vessel contains a number of concentric stainless steel shields to provide alternate layers of steel and water to reduce the gamma radiation level in the pressure vessel and so keep thermal stresses to an acceptable value.



Plan showing arrangement of core.

Control

The control system utilizes 16 control rods and a regulating rod. Four of the control rods are " black," i.e., totally neutron absorbing; the remaining 12 are " grey," designed

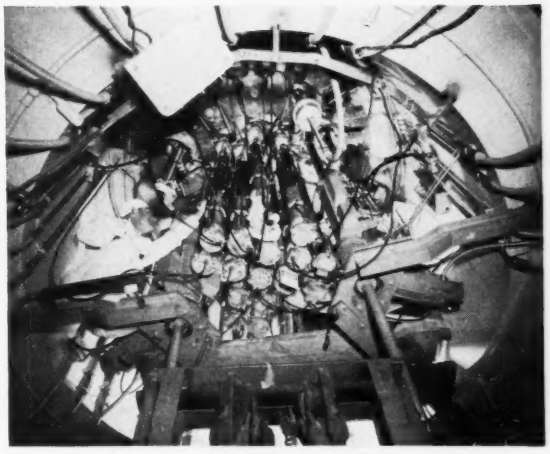


Simplified flow diagram of cooling arrangements.

so that the absorption and scattering cross-sections approximate closely to those of a normal fuel element, but without, of course, any fissionable material, and are designed so as to give minimum flux distortion. The 12 " grey " rods control about 12% reactivity compared with 13½% for the four " black " rods which, incidentally, are expected to be used as safety rods only, and not part of the regular control plan.

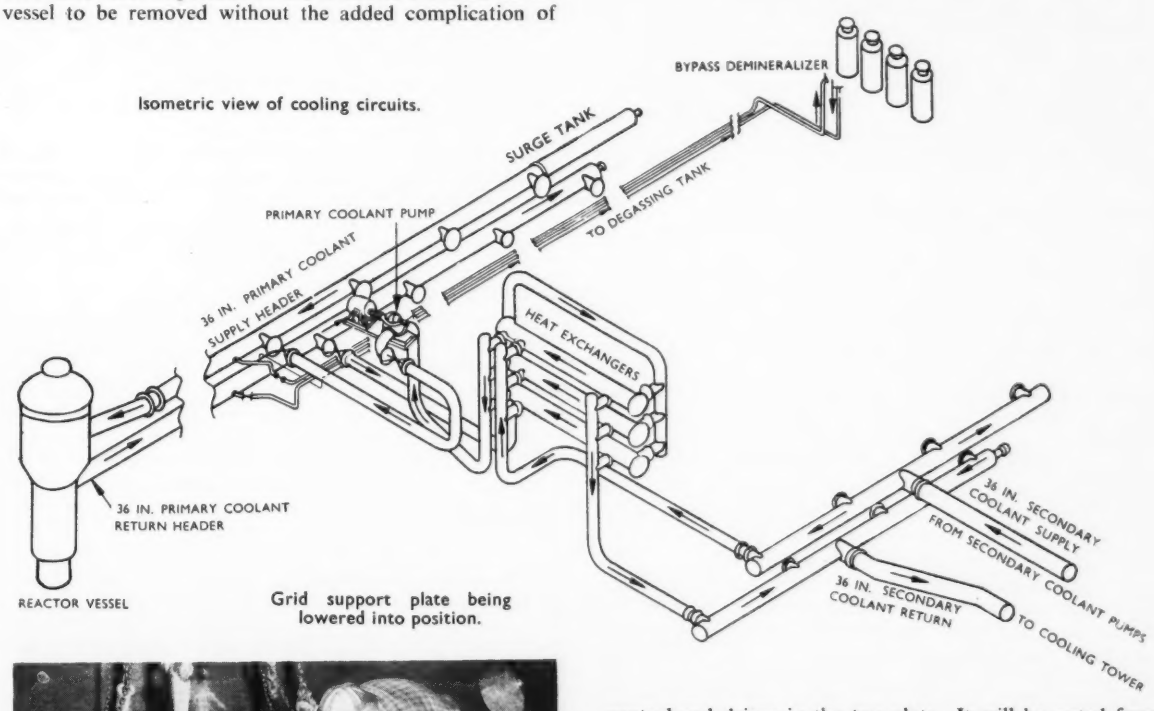
The regulating rod, located in the beryllium reflector is circular, approx. 1¾ in. dia, and made from stainless steel containing boron. This is designed to control about 0.3% reactivity, and is automatically worked by a servo system to compensate for small changes in load and keep a constant power level.

The control rod drives can be seen in a semi-finished state in one of the accompanying illustrations taken from the lowest point of the reactor—the control rod service room below the basement level. Bottom mounting and upward operation of the control rods necessitate a long rod with a high inertia; on the other hand it facilitates the use of gravity for the dropping of the rod into the core and, most important of all, it allows the head of the vessel to be removed without the added complication of

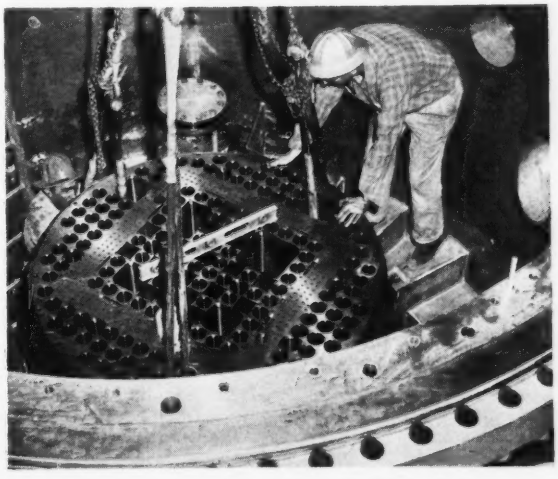


Control rod drives showing close mounting centres.

Isometric view of cooling circuits.



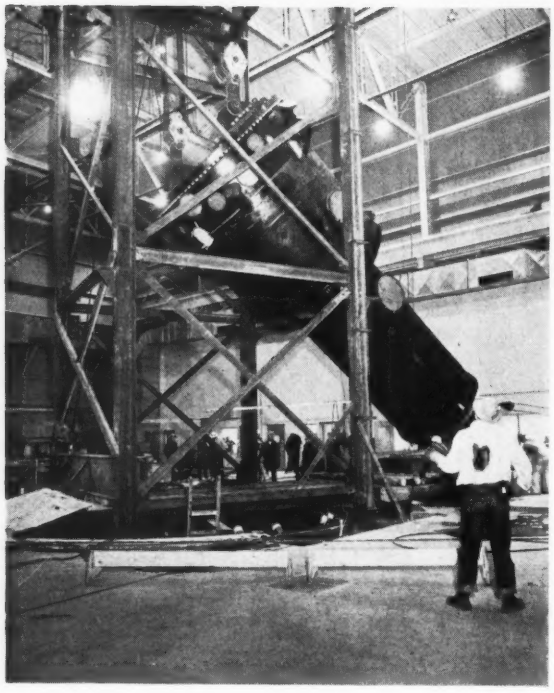
Grid support plate being lowered into position.



control rod drives in the top plate. It will be noted from the illustration that the close mounting centres required by the design has been achieved by removing the motors from the drives and disposing them in radial formation around the grouped buffer mechanisms.

Reactor Cooling

The main flow of coolant (demineralized water) in the ETR is downwards from the top header through the core, and reflector system and up again through the thermal shield area, to leave at the lower header. The coolant flows through 36-in. pipes to shell-and-tube type heat exchangers, the primary coolant being on the tube side. The total flow through the reactor is approximately 44,000 gal/min, the inlet and outlet temperatures being 110°F and 138°F. The water is pressurized, to prevent any



Pressure vessel being lowered into position during erection. This operation was completed in less than 4 hours.

possibility of boiling in the core, since the maximum surface temperature of the fuel plates is approximately 280°F and the heat flux is so high (more than 10^6 B.t.u./ft^2,h) that any bubble formation might lead to burn-out of the elements.

The heat exchangers are arranged in four banks of three exchangers in parallel. The exchanger units are arranged in counterflow and have fixed double tube plates, the space between the double plates being connected to a drain, to prevent any leakage from primary to secondary side at the ends of the tubes. All parts in contact with primary water are stainless steel.

There are four primary pumps, each having the suction connected to a heat exchanger bank; the discharge sides are connected to a common header. The pumps, of the horizontal split-case centrifugal type with bottom suction and horizontal discharge, are constructed with carbon steel casings; the corrosion characteristics of cast steel and the small area of the pump casing compared with the remainder of the system make, it is felt, this course acceptable. The impellers are of stainless steel. There are also two emergency and shut down pumps, each rated at 2,000 gal/min.

Pressurization of the primary water is achieved by continuously pumping 300 gal/min into the system and allowing the required amount to escape through a back-pressure valve operated by a pressure controller. A pressure surge tank serves the dual purpose of cushioning the system during normal operation and furnishing reserve pressure capacity in case of system failure.

Degassing of the primary water is, of course, essential to prevent gas formation in the core, and this operation is combined with the pressurizing system, the flow from the back-pressure valve being sprayed into a degassing tank through nozzles.

The water is controlled to a purity approximately 0.5 ppm dissolved solids at a pH of 6.0 by the use of a demineralization plant, consisting of a bank of four ion exchange columns, each containing 30 cu. ft of resin, one bed being anionic, one cationic and the other two mixed, the pH of the system being controlled by varying the flow through each section. The plant is capable of handling a by-pass flow of 100 gal/min during normal operation or 300 gal/min for short-term operation, for fission product removal necessitated by, say, a damaged fuel element.

Flow control through the reactor is effected by two valves, one a 36 in. motor-operated butterfly throttle valve in the inlet line, and the second, a comparatively small valve controlling a by-pass line across the reactor, this valve being operated by a differential pressure controller.

Secondary Cooling

A secondary water system rejects the heat from the main heat exchangers to a cooling tower. The secondary water is treated, but not demineralized. The capacity of the system is some 632,000 gal, which includes the amount stored in the cooling tower pond.

The cooling tower is of the counter-flow induced-draught type, fabricated from redwood and partially covered by corrugated asbestos cement. It is made up of nine cells, and handles 43,000 gal/min from 110°F to 78°F. Circulation is by means of four two-stage vertical turbine pumps, each having a capacity of 9,550 gal/min. Three emergency and shut-down pumps are also provided, these also being used for providing utility cooling water.

Make-up due to evaporation averages about 3% of the total flow, or about 1,500 gal/min. Raw water is taken from deep-well pumps and treated with inhibition, pH being controlled by sulphuric acid to between 6.3 and 6.7. Chlorine is used to control slime and algae.

Shielding

As indicated in the cut-away drawing, the biological shielding provides an integral part of the support for other portions of the building (e.g., the console floor). Magnetite concrete was considered the most economical for the site, this having a density of approximately 1.5 times that of conventional concrete. The cylindrical shield around the reactor itself is 8 ft thick, notched at the canal. There is an additional thermal shield between the reactor vessel and the concrete, in the form of a steel-walled lead-filled shield with a stainless steel cooling coil.

Thin spots in the shielding, such as the bottom of the fuel element discharge sump where it overhangs the sub-pile room, are provided with additional shielding in the form of thick steel plates.

It was originally intended to make the removable shielding at the top of the reactor of cast-steel, but it was eventually decided to use circular discs and rings, supported on block segments made from magnetite concrete, with steel corners and partial protection. Throughout the aim of the design has been to keep each piece within the limits of the 30-ton overhead crane.

The sub-pile room has walls 4 ft thick, the door being of laminated steel 18 in. thick, weighing 15 tons.

Additional shielding for the control rod access room below is provided by the control rod mounting plate and its supporting walls.

The coolant pipe tunnel is, in effect, a deep box girder with a 50 ft span and walls 4 ft thick. Although the principal radioactive component in the cooling water is normally N^{16}, with a half-life of only 7 sec, it emits a powerful gamma, and heavy shielding was considered necessary for the heat exchangers and pump houses. Conventional aggregates have been used for much of this construction.

SEMI-CONDUCTOR PROGRESS

(1) Silicon Transistor Manufacture at the New Bedford Plant of Texas Instruments, Ltd.

Capt. Christopher Soames with Mr. Dudley Saward and the Mayor of Bedford, inspecting the operation of attaching the centre lead to a transistor bar.

CLEANLINESS almost akin to surgical asepsis is the prevailing impression gathered from a visit to the new plant at Dallas Road, Bedford, of Texas Instruments Ltd., where production of silicon transistors has already commenced. When, however, one considers the proportion of impurities that will change the characteristics of a transistor, the precautions taken against extraneous additions do not seem out of place.

As is generally known, the silicon transistor has considerable advantages in certain situations, notably in high ambient temperatures, satisfactory working being possible up to 150°C. The first silicon transistors were made commercially available by Texas Instruments Inc., the parent company, in 1954.

Crystal Growing

The first step in manufacture of a grown junction transistor is the production of the crystal which must, of course, consist of three regions of different purity, with sharply-defined junctions. Crystal growing takes place in machines of the company's own design, rather resembling a drill press, with the chuck arranged for simultaneous slow rotation and withdrawal from a crucible of molten silicon. The chuck is "seeded" with a small crystal which is dipped into the melt and slowly withdrawn, bringing out a crystal shaped rather like a flattened onion. The crucible is heated by an R.F. induction unit, and both it and the rotating head are enclosed in a quartz shield, in an atmosphere of argon. A feature of particular interest is the arrangement made for adding the impurities at a controlled rate and a definite time to produce the sharply-defined zones required. The impurities, which are in pellet form, are placed in tubes at the top of the machine and released at the appropriate moment, by gear trains driven from the pulling head, dropping down a tube into the crucible.

Cutting

The crystal is then cut, first into vertical slices and then into 0.02 in. square bars, by ultrasonic cutting tools using diamond dust abrasive. The bars, each containing the base layer in the centre, are then given an acid pickle and proceed to the assembly line.

The first operation is a check test before any assembly work whatever is carried out. This is a very rapid test using a two-pronged probe laid across the bar, the characteristic being shown on a c.r.t. and any specimens whose reverse-voltage characteristic is not satisfactory are rejected.

Assembly

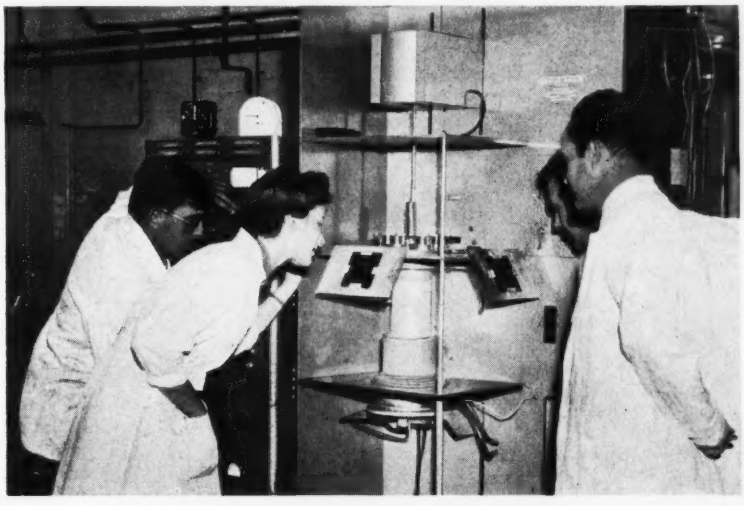
Satisfactory specimens then have the centre connection i.e. to the base layer, attached. This, as can be imagined, is an exceedingly delicate operation which is effected by actual fusing of the connection wire into the bar which is resistance-heated up to the correct temperature. An inert atmosphere is maintained around the bar during the operation, which is observed by the operator through a binocular microscope.

A complete transistor unit (approximately full size).

Next, the ends of the bar are tinned by being fluxed and then dipped into molten solder; this is also carried out in an inert atmosphere. The bar is then soldered to the connecting wires inside its case (a small gold-plated pressing with glass insulating inserts), and a further acid pickle removes all traces of flux. The final assembly operation is the closure of the case by a metal lid; resistance welding is used for this operation.

A formidable series of tests must be met before the unit is considered complete, this including temperature cycling at extremes of humidity; and mechanical rumbling and vibration tests.

As previously mentioned, extremely clean conditions are maintained for each operation. Raw materials for crystal growing, for example, are batched out in an air-conditioned balance room while in most operations, the necessity for preserving an inert atmosphere automatically guarantees cleanliness, glove-box techniques being used for certain operations.



Instruction in the technique of crystal growing.

SEMI-CONDUCTOR PROGRESS

(2) Power Rectifier Developments at Westinghouse

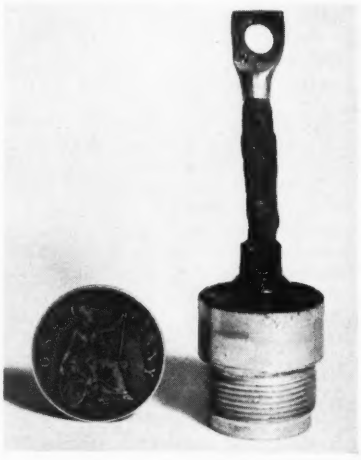
A PRIVATE exhibition held by the Westinghouse Brake and Signal Co., Ltd., at their Chippenham works provided an opportunity of observing the trend of developments in the applications of semi-conductors to the power field.

Rectifier Developments

In order to put recent developments in the rectifier field into proper perspective, it is necessary to glance briefly back into the early history of the metal rectifier. It was, actually, as far back as 1920 that Dr. Grondahl of the Union Switch and Signal Company discovered that layers of copper and cuprous oxide possessed asymmetrical conductivity, and the copper oxide rectifier was commercially available from about the mid-1920s. In the late 1920s it was discovered that selenium had comparable qualities but it was not until the late 1930s that the selenium rectifier became commercially available under the trade name "Westalite." The improved back voltage characteristics and the lower forward voltage drop widened the field of rectifier applications, and selenium rectifiers have been built up to nearly 9 MW capacity. Later still, came the germanium rectifier which again shows increased efficiencies for many applications. Last of all, the silicon rectifier is being developed in larger sizes, and, on account of its higher back voltage characteristics and its ability to withstand considerably higher operating temperatures, offers a completely new range of rectifier characteristics.

The progress over some 30 years can be roughly summarized by considering the variation in cubic content of rectifiers. In the 1920s, with a copper oxide rectifier an output of about 0.5 kW was obtained for every cubic foot of rectifier volume. This figure was progressively increased to 6 kW with selenium, 18 kW with germanium, while with silicon an output of 50 kW can be obtained.

It should not, however, be assumed that each new development supersedes the previous one: nothing could be farther from the truth. Each new development has, rather, extended the field of rectifier applications. Every type has, in fact, still its own particular field and it is becoming more and more a specialist's job to decide which type is the most suitable for a given set of conditions. The copper oxide rectifier which, incidentally, has recently been developed with improved characteristics, is still the best proposition for low-voltage, low-current applications where selenium characteristics are not required. Similarly, germanium would be preferable to silicon for a wide portion of the ranges since its forward voltage drop is lower. This would not apply, of course, where the voltage was such that a single silicon unit could deal with a situation that would require two germanium rectifiers in series.



Some idea of the compactness of the silicon rectifier can be gauged from this view of a silicon diode rated at 350 amp.

Manufacture of Silicon Rectifiers

The silicon rectifier, the latest to be marketed by Westinghouse, has been developed in conjunction with the Westinghouse Electric Co. in the U.S.A. with whom the British company are now associated in the semi-conductor field. A new plant has been built down at Chippenham which will be entirely devoted to the production of germanium and silicon units, and has been designed for that purpose.

The conditions required for the successful manufacture of germanium and silicon diodes impose a degree of cleanliness that, considered even by "clean factory" standards, would appear little short of fantastic. The crystal-growing operation also requires the maximum freedom from vibration, and the site has been chosen remote from the main works, in a position where the minimum amount of airborne dust is to be expected, a grove of trees offering a natural windbreak.

The construction of the building, with regard to floor and wall surfaces, etc., is such as to minimize dust formation and all windows are of the non-opening type, ventilation being by means of an air-conditioning plant housed in a separate building. Air supplied to the general working area is filtered by Vokes filters to a maximum particle size of 5 microns; for the area in which crystal growing takes place filtering is carried out to 1 micron.

Crystal growing follows conventional practice, pulling taking place vertically from a molten mass in an R.F. heated crucible. The operation takes place *in vacuo*, instead of an inert atmosphere.

The crystal, in cylindrical form, is sliced into thin discs by a diamond wheel and the discs, mounted on composition blocks, are cross-cut into thin squares, or "pellets."

The rectifying zone of a silicon unit is the layer formed by the diffusion of aluminium into the surface of the silicon pellet. The actual construction is, however, more complicated than this, the layers between the two terminals being as follows:—

Anode rod, solder, nickel-plated molybdenum, aluminium, silicon, tin, n.p. molybdenum, solder, base support. The solder used is a high-temperature "comsol." The purpose of the molybdenum is to prevent cracking of the silicon crystal during the diffusing process, owing to the widely different expansion coefficients of aluminium and silicon. Some idea of the compact dimensions of the silicon rectifier is shown in the accompanying illustration. Silicon rectifiers, in general, have extended fins for cooling purposes, unless air-blast or water cooling is preferable.

Other Exhibits

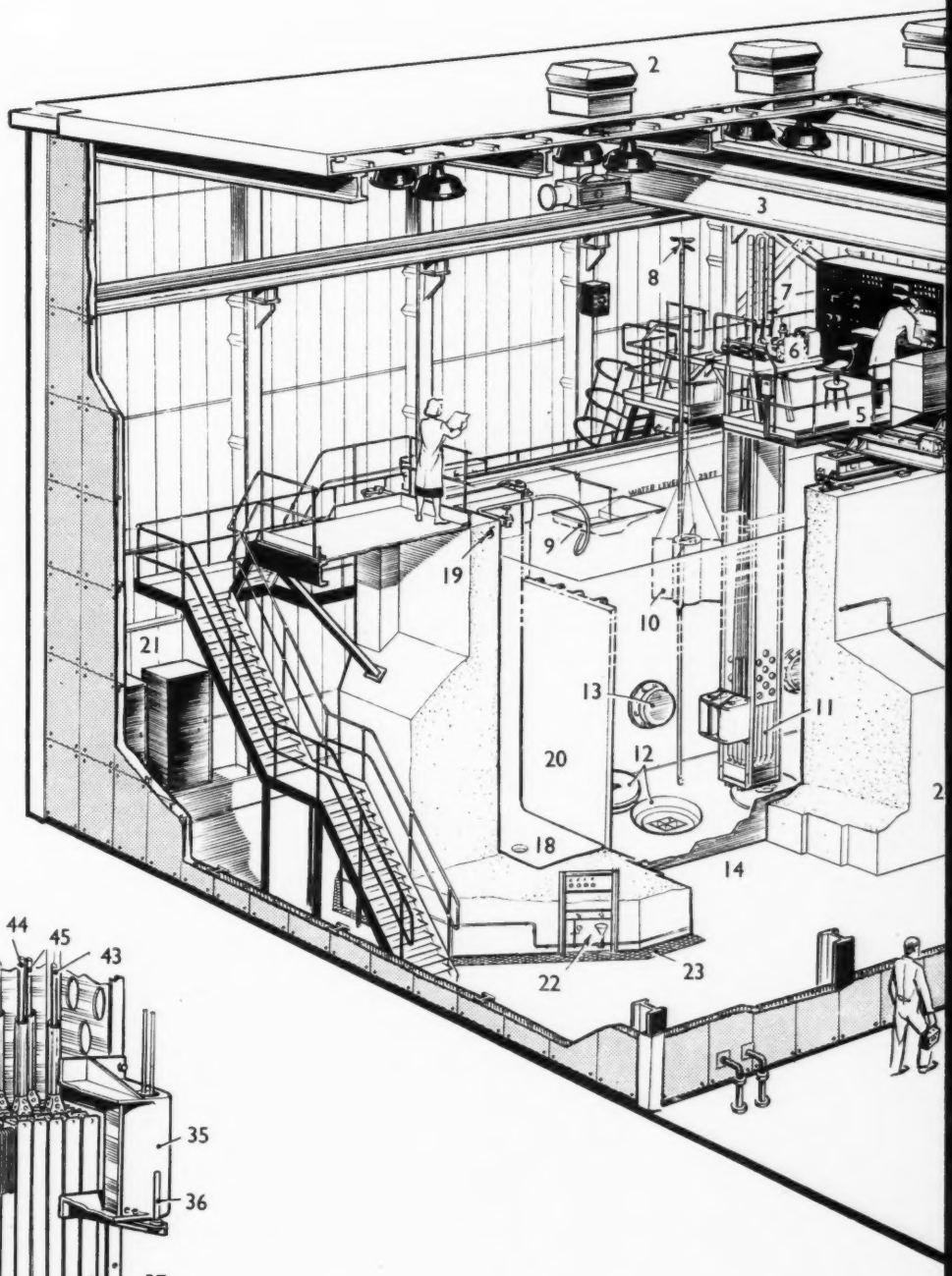
A very wide range of rectifier equipment was on view, a notable example being a 3 phase silicon rectifier rated at 600 kW with air-blast cooling.

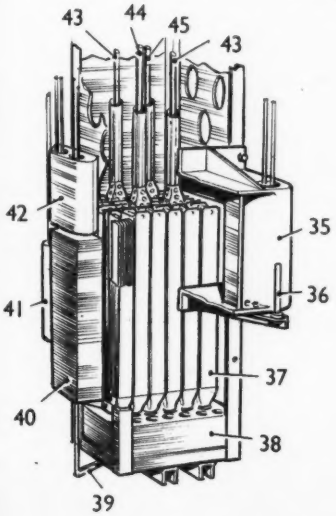
An exhibit of considerable interest was a pair of power transistors made in the research laboratory. The power transistor in large sizes opens up fascinating vistas in the field of power control.

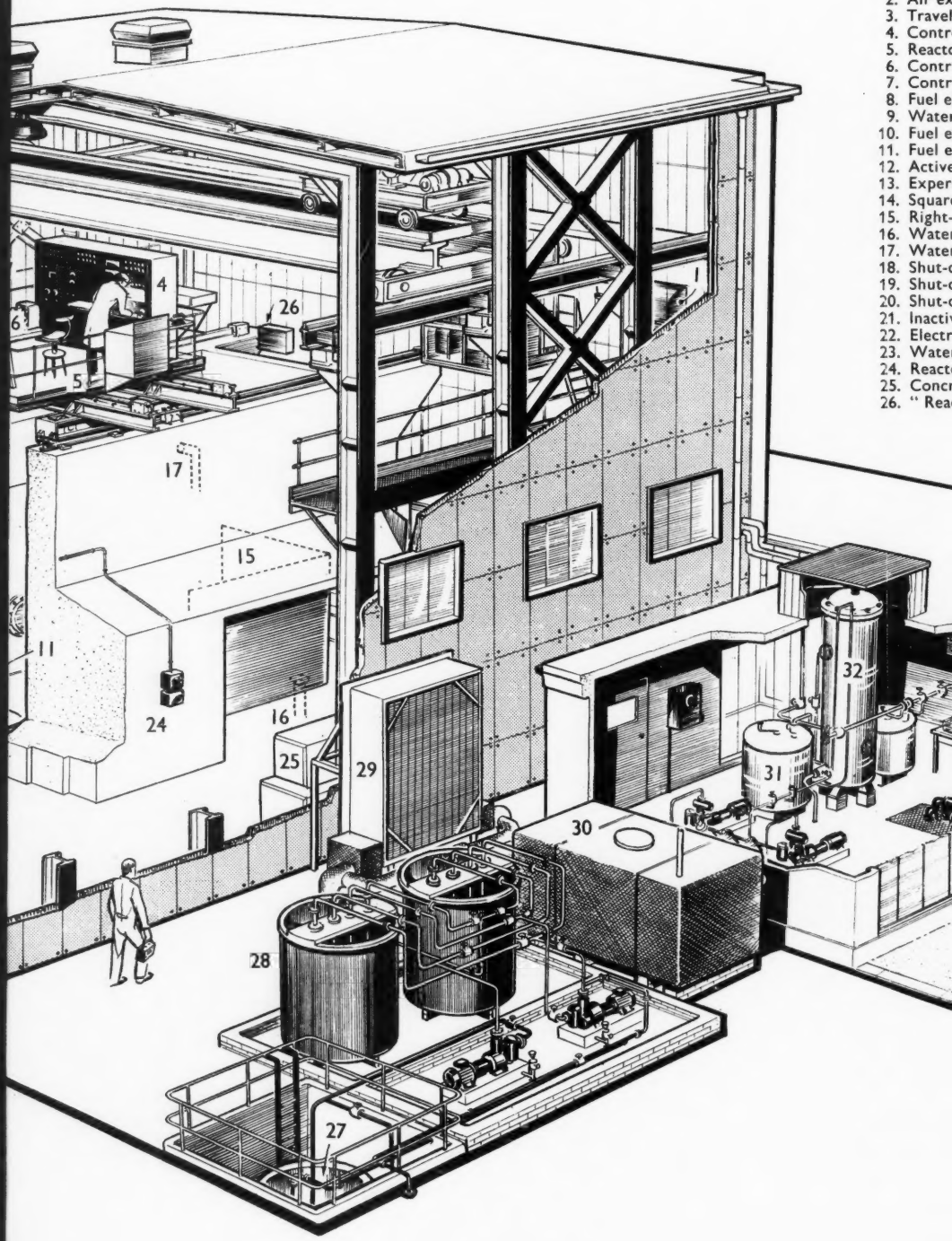
To the specialist nuclear engineer, power rectifiers are of marginal interest although the field of auxiliary equipment is very wide. One direct application which will undoubtedly arise is the use of rectifiers for operating d.c. electromagnetic pumps in place of the homopolar generators previously considered, and here the rectifier appears to have possibilities that have not yet been thoroughly explored.

The World's Reactors

No. 15 LIDO







1. Fresh
2. Air ex
3. Travel
4. Contr
5. Reacto
6. Contr
7. Contr
8. Fuel e
9. Water
10. Fuel e
11. Fuel e
12. Active
13. Exper
14. Squar
15. Right-
16. Water
17. Water
18. Shut-o
19. Shut-o
20. Shut-o
21. Inacti
22. Electr
23. Water
24. React
25. Concr
26. " Rea

KEY

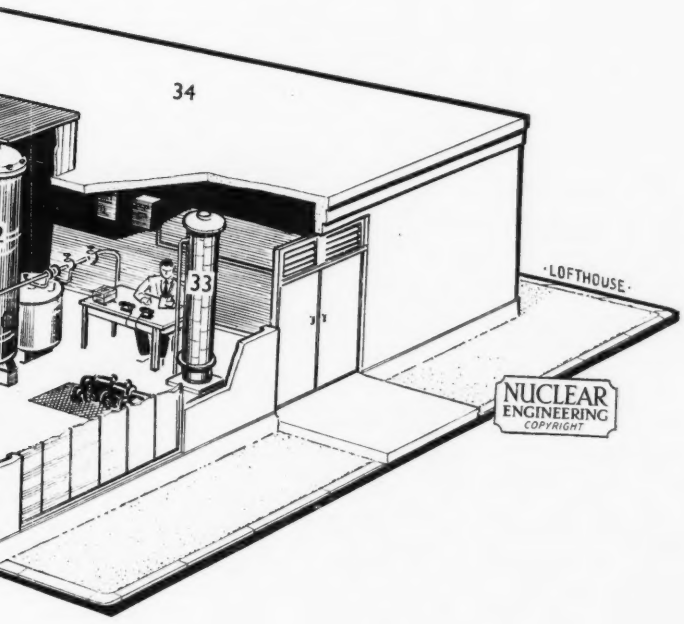
1. Fresh air inlet
2. Air extractions
3. Travelling crane
4. Control panel
5. Reactor trolley
6. Control and safety rod motors
7. Control rod rack covers
8. Fuel element handling tool
9. Water skimmer
10. Fuel element transfer bucket
11. Fuel elements in reactor core
12. Active fuel element storage pit and cover
13. Experimental beam hole
14. Square experimental panel
15. Right-angled experimental panel
16. Water inlet pipe
17. Water extract pipe
18. Shut-down bay water inlet pipe
19. Shut-down bay water extract pipe
20. Shut-down bay door
21. Inactive element storage cabinets
22. Electrical and water services
23. Water duct to sump
24. Reactor shut-down switch
25. Concrete blocks for experimental shield
26. " Reactor working " light panel

Water treatment plant

27. Active waste dump tank
28. Effluent delay tank
29. Water cooler
30. Water make-up tank
31. Regenerating vessel for ion exchange column
32. Regenerable ion exchange column
33. Non-regenerable ion exchange column
34. Office block

Reactor core detail

35. Log channel for ion chamber in lead shield
36. Lamp bracket
37. Fuel elements
38. Lattice plate
39. Fuel element locking gear
40. Graphite block
41. BF_3 counter
42. Shut-down ion chambers in lead shield
43. Safety rods
44. Fine control rod
45. Coarse control rod



The World

No. 1

TYPE:	Swimming
PURPOSE:	Shielding a
LOCATION:	A.E.R.E. H
OPERATION:	September
RATING:	100 kW.
FUEL:	Uranium e U–Al alloy Critical in Normal in
ELEMENTS:	M.T.R. typ Critical loa Active len Each plate incl Space betw
LATTICE:	Regular sq No. of latt
MODERATOR:	Light wate
REACTIVITY:	Normal lo
FLUX:	At 100 kW γ dose at
CONTROL:	Four plate Material: S Location: plat Reactivity fine
DRIVE:	Fine rod: Coarse an Max. rate
COOLANT:	Light wate Tank circu Max. oper Purificatio colu
MAIN TANK:	Material: c Internal di Water dep
SHIELDING:	Upwards: Sides: 7 ft
EXPERIMENTAL FACILITIES:	L-shaped p Square pa Panel deta wat 3 beam ho
CONTAINMENT:	None. Reactor lo

World's Reactors

No. 15 LIDO

Swimming pool.

Shielding and other medium flux expts.

A.E.R.E. Harwell.

September, 1956.

100 kW.

Uranium enriched to 46% U^{235}.
U–Al alloy, Al clad.
Critical investment: 3.25 kg U^{235}.
Normal investment: 3.35 kg U^{235}.

M.T.R. type with 13 plates/element.
Critical loading: 26–27 elements.
Active length: 24 in.
Each plate: 24 in × 2.875 in × 0.076 in, including 0.020 in thick Al cladding.
Space between plates: 0.124 in.

Regular square, pitch: 3.025 in.
No. of lattice plate positions: 36.

Light water.

Normal loading: 1% δk excess.

At 100 kW, central: $10^{12} n_t/cm^2,s$,
$1.5 \cdot 10^{12} n_f/cm^2,s$.
γ dose at core edge: 10^6 r/h.

Four plates, 2 safety, 2 control.
Material: S.S. clad Cd.
Location: moving in central gap in special element plates on each side Al only.
Reactivity control, safety: 1.5% each, coarse: 1.5% fine: 1%.

Fine rod: variable speed motor.
Coarse and safety rods: constant speed motors.
Max. rate of increase in k: 0.01%/sec.

Light water, natural convection through core.
Tank circulation through cooler: 2,000 gal/h.
Max. operating temp. 40°C.
Purification: 200 gal/h through regenerable ion e: column.

Material: concrete.
Internal dimensions: 28 ft × 8 ft × 24 ft deep.
Water depth: at 23 ft.

Upwards: 17 ft water.
Sides: 7 ft Portland cement.

L-shaped panel with two faces: 8 ft × 8 ft.
Square panel: 8 ft × 8 ft.
Panel details: two $\frac{1}{2}$-in Al plates, 2 in apart, separ: water and egg-box stiffener.
3 beam holes: 1 ft dia.

None.
Reactor located in catchment area.

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. *BEPO* (*April*, 1956)
No. 2. *CP5* (*May*, 1956)
No. 3. *NRX* (*June*, 1956)
No. 4. *DIMPLE* (*August*, 1956)
No. 5. *ZEUS* (*September*, 1956)
No. 6. *CALDER HALL* (*October and December*, 1956)
No. 7. *RUSSIAN* 5 *MW* (*November*, 1956)
No. 8. *DIDO* (*January*, 1957)
No. 9. *THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION* (*February*, 1957)
No. 10. *BERKELEY POWER STATION* (*March*, 1957)
No. 11. *BRADWELL POWER STATION* (*April*, 1957)
No. 12. *DOUNREAY FAST REACTOR* (*June*, 1957)
No. 13. *EBWR* (*July*, 1957)
No. 14. *RWE* 1 (*September*, 1957)

Technical Papers and Publications

Graphite in Nuclear Power Industry

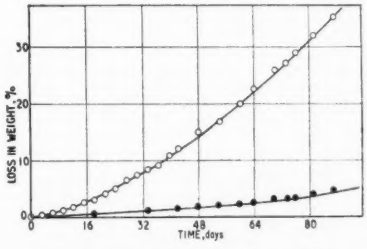
(The Graphite Symposium organized by the Society of Chemical Industry, Sept. 24-26)

In the October issue of Nuclear Engineering, *three papers presented at the Graphite Symposium organized by the Society of Chemical Industry were reviewed. A summary is given here of five additional papers presented at the same conference. These have been selected for special treatment as directly concerning the reactor programme, but for a full report on the conference, reference must be made to the Society.*

Compatibility Problems of Graphite Moderators. A. B. McIntosh, W. G. O'Driscoll and C. Tyzack U.K.A.E.A.I.G., Culcheth).

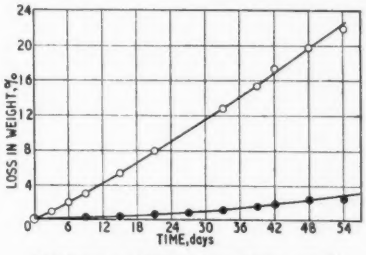
With higher ratings of gas-cooled graphite-moderated reactors compatibility problems of graphite and coolant become more serious. The main reaction in the Calder type reactor is the formation of carbon monoxide with the possibility of mass transfer of the carbon.

For sodium graphite reactors the compatibility of sodium and graphite is of considerable significance. Under reactor conditions, liquid sodium is incompatible with ordinary graphite as a result of physical rather than chemical interaction, although chemical corrosion can occur as a result of transfer of carbon to a constructional material. The most serious effect is a swelling of the graphite as a result of adsorption of sodium at temperatures in excess of 450°C.



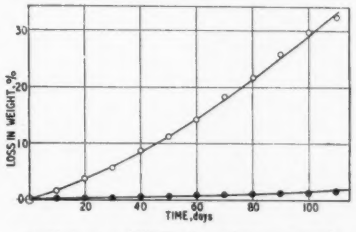
Oxidation at 700°C of specimens coated with high-density graphite (black circles). The white circles represent uncoated control specimens.

Although the oxidation rate of carbon by carbon dioxide at 500°C in out-of-pile conditions is small, the rate of reaction is increased under irradiation. It is desirable therefore to find a means of protecting the graphite, preferably without the inclusion of materials of high cross section. A number of metal and ceramic coatings have been investigated, including: Mg, Al, Mo, Zr, S.S., Ni, Spinel and Alumina. The test temperature adopted was 700°C, which represents in fact a bigger increase over Calder temperatures than is currently envisaged but is of assistance in obtaining rapid results. No satisfactory metal or refractory oxide coatings were developed, the coatings showing either porosity or a tendency to spall. Two other surface treatments showed promise, the first of these consisted of a layer of high density graphite (see following paper) and the second consisted of the gas phase deposition of a layer of silicon carbide (developed by the Morgan Crucible Co., Ltd.). The two methods yielded reductions in oxidation rate at 700°C and are shown in the accompanying curves.



Oxidation at 700°C of specimens coated with silicon carbide (black circles). The white circles represent an uncoated control specimen.

A different approach to the development of protective treatment which does not involve the coating of machined blocks or complete impregnation concerns the introduction into graphite of small quantities of phosphorus compounds. A suitable treatment consists of the exposure of graphite to the vapour of P_2O_5 followed by rapid heating to about 1000°C under argon. A curve of



Oxidation at 700°C of specimens treated with trimethyl phosphate (black circles). The white circles represent untreated control specimens.

the change in oxidation rate resulting from an alternative method based on exposure to the vapour of refluxing trimethyl phosphate is shown. The potentialities of the phosphorus treatment are thought to be considerable. It is a bulk treatment involving no dimensional changes and one which can be applied before or after machining. It may also be effective in limiting the reaction of graphite with other coolants such as hydrogen. Moreover, the low capture cross section of P for thermal neutrons combined with the small quantity introduced should make fuel enrichment unnecessary and the concentration of the stable isotope would fall by only 0.5% after 10 years irradiation.

Preliminary experiments on the gases evolved from graphite indicate a significant concentration of hydrogen and a programme to assess the effect of such degassing on the mechanical and physical properties of barrier metals such as zirconium is under way.

The Preparation and Properties of High-Temperature Pyrolytic Carbon. A. R. G. Brown and W. Watt (R.A.E., Farnborough).

The paper gives an overall picture of the preparation, properties and structure of the deposited carbons produced by the high-temperature pyrolysis of benzene, methane and propane. After a brief summary of the information available in the literature a description is given of the apparatus which formed the basis for the experimental work. In essence this consists of a chamber of controlled atmosphere carrying a centrally disposed carbon electrode which can be heated electrically and on which deposition of pyrolytic carbon takes place. The three gases mentioned were investigated at different pressures and at different temperatures of the base rod.

After a deposition run the base rod was covered with a layer of deposited carbon normally thicker at the centre than at the ends, the variation being attributed to temperature gradients along the axis of the specimen. An exception to this general result occurred at 1900°C when specimens were normally tapered from top to bottom but no explanation of this has been put forward. At low temperatures, a black sooty deposit was formed but at temperatures over 1800°C films were hard and dense. These films contained trace amounts of hydrogen.

The variation of the density of the deposited carbon with the temperature of deposition appears to be a fundamental property and largely independent of the hydrocarbon used as source. This suggests that the phenomenon is one associated primarily with the surface on which deposition takes place and it is suggested that the density is largely determined by the surface mobility of

the carbon atoms immediately after deposition. A characteristic curve for density of deposit against temperature showed a minimum at 1700°C with a sharp rise up to about 2000°C at which temperature the curve flattens off. The rise in density below 1700°C has not been investigated in detail. Maximum densities achieved by the deposition processes were in the region of 2.22 g/cm^3. The rate of deposition is a function of the hydrocarbon composition and of the pressure and temperature.

The apparatus could be used for either batch deposition processes or for continuous deposition and for investigation of the physical properties of the deposits, square or rectangular cross sectional base rods were used. Microscopical examinations of cross sections of deposited carbons reveal a characteristic structure. Carbons deposited at 2000°C show the beginning of a finer type of structure which becomes clearly marked in the carbons produced at 2100°C but in all cases the structure consists essentially of cones of material growing from the base rod. X-Ray examination showed that deposited carbon was oriented so that the hexagonal layers lay parallel to each other and to the surface of the original substrate. The effect of heating the deposited carbon to temperatures above 2500°C is characterized by an increase in density more pronounced in the case of specimens produced at the lower temperature of deposition and with therefore originally a lower density. Carbons originally deposited at temperatures of 2100°C and 1600°C heat treated at 2800°C give final density figures of 2.24 g/cm^3 and 2.14 g/cm^3 which should be compared with a final density figure of 1.73 g/cm^3 from carbon deposited at 1800°C.

Physical and Mechanical Properties of Graphite Moderators. A. B. McIntosh, T. J. Heal and A. Cowan (U.K.A.E.A.I.G., Culcheth).

Normal reactor graphite has a bulk density in the range 1.7-1.8 g/cc as against a theoretical density derived from the perfect graphite lattice of 2.26 g/cc. The possibility of modifying the properties of pile graphite therefore exists if the need is shown to be economically justifiable.

The principal mechanical requirement is compressive strength at the present time, to allow the graphite to support the weight of the graphite structure above. More advanced designs may require the graphite moderator structure to support the fuel elements which will impose bending loads on the material. Amongst the physical properties, the density, the coefficient of thermal conductivity and of thermal expansion are significant. The electrical resistivity can be shown to bear an empirical relationship to the thermal conductivity and may therefore be used as a sorting test. There is evidence that changes in thermal conductivity bear a relationship to the quantity of stored energy built up by the neutron flux.

Previous work has shown that the mechanical strength of graphite increases with temperature, the increase being approximately linear at low temperatures. Values of ultimate tensile strength at room temperature are of the order of 2,000 lb/in.^{2} and compressive strength 3,000 lb/in.^{2} increasing by factors of about 2 at 2500°C. Young's modulus is also dependent upon crystal size and according to the G.E.C. laboratories the temperature coefficient of Young's modulus is also a function of crystal size. An increase in the modulus value by a factor of 2 and the modulus of rupture by 1½ has been reported resulting from irradiation levels of the order of 5×10^{20} nvt.

The elastic modulus and the square of the electric conductivity and tensile strength increase linearly with density while thermal conductivity increases almost linearly with the density up to 1.65 g/cc and then linearly again but at a greater rate with densities 1.65-1.75 g/cc. An irradiation dose of 5×10^{20} nvt has no appreciable effect on density although resistivity increases by a factor of about 3.

Comparison of the compressive strength in longitudinal and transverse directions for British reactor grade graphite shows that the former may be greater, equal to or less than the latter. The average result is 1.97 ton/in.^{2} with an average difference between the two directions of 0.028 ton/in.^{2}. Block to block variation is also significant. No significant variation from block to block has been found in measurements of the transverse modulus of rupture. Variations have been found in compression strengths of samples taken from single blocks which could not be attributed to differences between inner and outer material.

Our present knowledge however of the physical and mechanical properties of graphite has been shown to be inadequate for the purpose of designing advanced thermal reactors.

The Harwell Experimental Graphite Plant. M. S. T. Price and F. W. Yeats (A.E.R.E., Harwell).

To examine in detail the results of changing the composition of raw materials and the method of treatment at various stages in the production of graphite, an experimental plant has been built at Harwell. Although final block sizes of 8 in. sq are used in the Calder Hall type reactors, it was decided that, for experimental purposes, extruded rods, 4 in. diameter and 18 in. long should be adopted. A constant batch size throughout the series of experiments of 250 lb was chosen. In brief, the plant consists of a petroleum coke storage which feeds crushing, grinding and sieving stages. Facilities for this were already available in the mineral pressing laboratory situated in the same building. Coal tar pitch is fed from the storage bins to a dis-integrator and an analysis of the types available indicated that a 12-in. machine with a cruciform beater and a rotor speed of 6,000 r.p.m. incorporating a bar grid of $\frac{1}{16}$ in. or finer would be suitable. Several types of blender are available for mixing the two components and a double cone type was found to be the most satisfactory for the particular plant in mind. A sigma-bladed dough mixer was used for the heat mixing plant of 44 gal capacity. This was fitted for vacuum mixing and could be heated by steam up to 165°C. A 500-ton extrusion press was installed although preliminary calculations indicated that a 300-ton would suffice.

Pressurized baking furnaces were included to determine the effect of varying pressure in the baking process on the final graphite density. Two furnaces were designed with maximum operating temperatures of 1050°C and 1300°C the first of which incorporated nickel chrome wire windings and the second molybdenum. The graphitizing furnace was of unconventional design and consisted in effect of a graphite element surrounding the samples mounted in a vacuum chamber.

Vacuum tamping of the hot mix using the main extrusion ramp was investigated and showed that an increase in density of the extruded material resulted. Similar tamping under atmospheric pressure resulted in swelling after extrusion.

Investigation of baking under pneumatic pressure showed clearly an increase in density but perhaps more important an increase in the uniformity of the density of the product. In addition the process reduces scale effects such as the dependence of weight loss on sample sizes and permits baking at rates which, under normal atmospheric conditions, would induce unacceptably high weight loss. With vacuum tamping and pressure baking a density gain of at least 0.10 g/cc can be obtained compared with conventional procedures, when processing orthodox material of green density around 1.76 g/cc. In this way graphite density of 1.75 g/cc has been achieved without impregnation.

The Flow of Gases Through a Fine-Pore Graphite. J. M. Hutcheon and B. Longstaff (A.E.R.E., Harwell) and R. K. Warner (Australian A.E.C.).

The flow of various gases has been measured through a fine-pore, commercial graphite, perpendicular to the extrusion axis of the material under a wide range of mean pressures, pressure drops and temperatures. The results have been correlated by an equation for simultaneous viscous and slip flow of a gas in a porous medium. Average values of the viscous and slip permeability coefficients of the graphite were found to be $1.63 \cdot 10^{-12}$ cm^2 and $1.12 \cdot 10^{-7}$ cm^2 respectively and the coefficients were independent of temperature. From the experiments it has been possible to deduce values for the mean pore size, surface area and tortuosity factor of this graphite.

One of Vienna's famous concert halls, the Konzertnaus was turned over to the first general conference of the new International Atomic Energy Agency for its meetings.

World News

International

First general conference of the International Atomic Energy Agency was formally opened in Vienna on October 1. To facilitate the work of the Agency, Vienna's largest concert hall, the Academy of Music, was granted extra-territorial status. The conference has subsequently agreed that Vienna should be the permanent home of the Agency. Mr. Sterling Cole, a former chairman of the Joint Atomic Energy Committee of the U.S. Congress, was unanimously elected to the post of director-general for the next four years. Dr. Karl Gruber, former Austrian Foreign Minister and at present Austria's Ambassador to the U.S., was elected president of the conference.

In addition to the thirteen members of the Board of Governors already appointed the conference elected the following seven members representing regions: Argentina (Latin America), Italy (Western Europe), Rumania (East Europe), Egypt (Africa and the Middle East), Pakistan (South Asia), Indonesia (S.E. Asia and the Pacific) and South Korea (Far East). Turkey, Guatemala and Peru were elected to the Board without regard to areas.

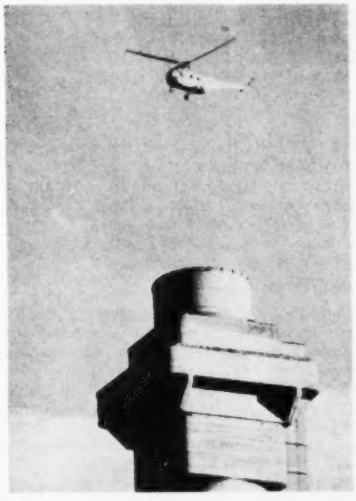
In the course of the conference various delegations have made offers to supply uranium to the Agency. For example, the U.S. has offered 5,000 kg. of U^{235}, Britain 50 kg., and U.S.S.R. 50 kg. Portugal proposes to offer 100,000 kg. of uranium oxide which should produce about 700 kg. of U^{235}. In addition to the 5,000 kg. of U^{235} the U.S. has offered to match the contributions of any other countries until July, 1960.

At Cannes on September 29, an international congress of scientists from 33 countries called for the banning of experimental nuclear explosions and the production of atomic bombs. Professor Antoine Lacassagne told the congress that all radiation which was strictly unnecessary should be cut down; perhaps, in the future, nuclear power stations should be banned.

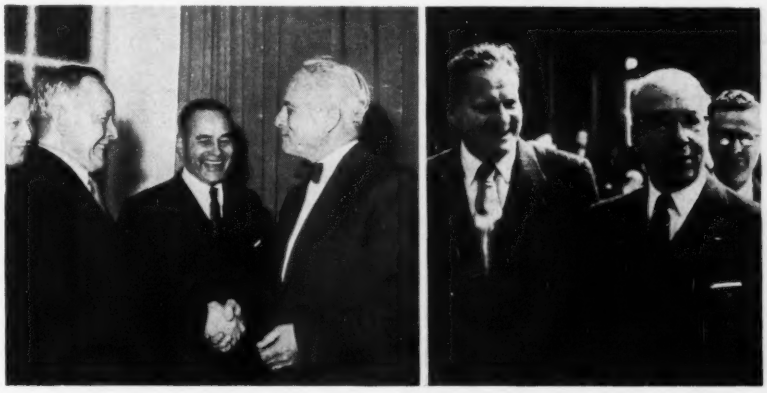
United Kingdom

First victim of the Government's restriction of investment expansion may be the projected nuclear power station at Trawsfynydd. A spokesman for the C.E.A. said that although a final decision had not been made, there might be a delay of from 9 to 12 months in seeking tenders. The Government plans an overall reduction in spending of between £300 million and £350 million in the next two years.

Windscale No. 1 reactor overheated on Thursday, October 10, and combustion of some fuel elements took place. At the time of the incident the reactor was shut down but the overall temperature had been raised to release the Wigner growth: in addition, some experimental equipment was included in the pile. A committee of inquiry has been set up under Sir William Penney to investigate the accident. Those findings which are not influenced by the Official Secrets Act (as a plutonium producer, Windscale is a military installation) are likely to be made known at the beginning of November. Although the filters at the top of the stack kept back a considerable amount of activity, a significant quantity was deposited over the surrounding countryside—particularly iodine. As a safety precaution, milk from an area of 40 square miles (later extended to 200 sq. miles) was banned for consumption. Maximum activities recorded in milk were six times m.p.l., i.e., the activity level worked out as representing the safe concentration for a lifetime intake. Maximum levels of strontium recorded were approximately one-fifth of the m.p.l.—again a lifetime intake figure. All three countries known to be operating air-cooled piles have now experienced a fuel burn.



On Saturday, October 19, a helicopter was used in tests to determine the degree of radioactivity in the vicinity of the No. 1 reactor stack at Windscale.



(Left) Professor V. S. Emelyanov of the U.S.S.R. welcomes Mr. Sterling Cole on his appointment as director-general of the new I.A.E.A. Dr. Ralph Bunche is shown centre. (Right) President of the first conference Dr. Karl Gruber of Austria and Mr. Lewis Strauss, chairman U.S.A.E.C.

Although food preserved by irradiation is not likely to be seen in the shops for some years, there are fascinating possibilities for the process. That sums up the conclusions reached by the Symposium on Irradiated Foods, held at Cambridge, on September 26 and 27. About 100 British and 20 overseas delegates attended the symposium. They included two main groups—the Low Temperature Research Station of the D.S.I.R. at Cambridge and the Technological Irradiation Group of the Isotope Division at Harwell.

Because the fast breeder reactor at Dounreay is nearing completion U.K.A.E.A. will not accept applications for visits to the establishment for several months.

Caithness education committee are hoping to get more financial assistance towards the erection of a technical college at Thurso. Already the committee has agreed to the construction of a new £350,000 senior secondary school at Thurso arising from the Dounreay project. They, therefore, feel that there is a case for more than an 85% grant towards the £33,000 estimated cost of the college.

To supply Diesel fuel to the Dounreay area, Scottish Oils and Shell-Mex Ltd. have opened a new £200,000 oil depot at Scrabster, near Thurso.

Exhibition dealing with the research and development work which is being undertaken at the Dounreay establishment opens at 10 Carlton House Terrace, London, S.W.1, on November 5, for three days (10 a.m. to 8 p.m.).

Some 120 directors and senior executives from British industry attended a three-day course on radio isotopes in industry at Harwell Isotope School at the end of September.

Following a tour of hydro-electric schemes in Scotland, industrial centres and power stations in the U.K., including Calder Hall, a Soviet delegation returned home during October. At a press conference on October 10, Mr. F. G. Loginov, chief deputy of the Ministry of Electric Power Stations of the U.S.S.R., said that Russia's electrical industry could benefit by the import of British goods.

Lord Salisbury will open an extension of the Radiochemical Centre at White Lion Road, Amersham, on November 1.

Sir John Cockcroft left the U.K. for a visit to the United States on October 10.

"Atom, 1957"—an exhibition staged jointly by the U.K.A.E.A. and *The Sunday Times*—was staged at Park Lane House, London, W.1, during October. Visitors saw a selection of models of the new British nuclear power stations and applications of radio isotopes in industry. Great interest was shown in careers in atomic energy.

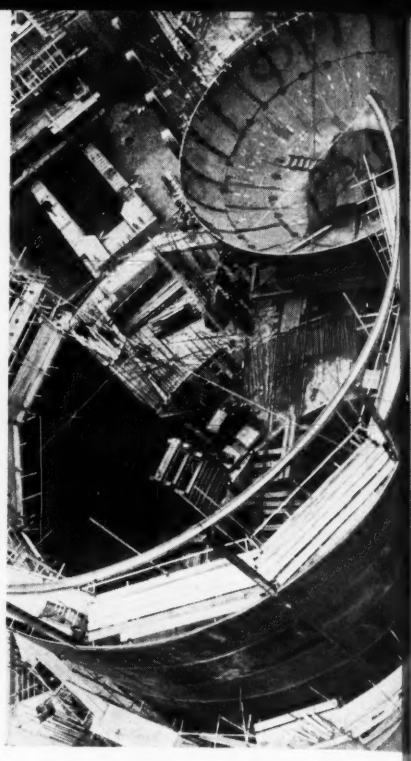
As part of the proposal to lay a submarine cable between England and France (already approved by the Minister of Power) it will be necessary to construct a 275 kV overhead line between Northfleet and Dungeness, for commissioning by the winter of 1960. It is understood that a site has already been selected in the Dungeness area for a nuclear power station which will be commissioned two or three years later.

Africa

Seventeenth uranium plant to be started in five years was opened on October 8 at Buffelsfontein, near Klerksdorp, west Transvaal, by the British High Commissioner, Sir Percivale Liesching, and the United States Ambassador, Mr. Henry A. Byroade. The plant, which will cost more than £5½ million sterling, is to produce uranium oxide.

Canada

Dr. Wilfrid B. Lewis, vice-president for research and development, Atomic Energy of Canada, Ltd., said on October 9 that he had revised his forecast that Canadian nuclear power stations would be producing electricity economically by about 1962. He now thought this goal would not be reached until at least 1966 or, perhaps, 1970. A main reason for the delay was the difficulty in developing suitable metals. He believed that by 1980 it would be possible to build economic power reactors which could be sealed after construction and operate for ten years without being refuelled. Success of Canadian research will depend on results from the operation of an experimental power plant to be built near Chalk River and tests to be conducted on NRU, a research reactor of 200 MW now under construction.



The lower part of the first pressure vessel at Berkeley was moved into position on October 20. This section, welded up from curved and formed 3-in. thick plates, weighs 200 tons.

"Nautilus"—the U.S. Navy's nuclear-powered submarine has been taking part in N.A.T.O. exercises in the Atlantic. During a visit to Portland Mr. Duncan Sandys, Minister of Defence (standing by coil of rope, hands in pockets), and Admiral of the Fleet Earl Mountbatten of Burma (centre, looking up) went for a four-hour cruise. The captain of the "Nautilus," Commander W. Anderson, is facing Earl Mountbatten.

At Bradwell good progress is being maintained. This view shows both 1 and 2 reactors at the end of September. The plinth for No. 1 reactor has been completed.

On September 30 it was announced that the first fuel rod had been completed at the new Port Hope, Ontario, plant and nuclear laboratory of the AMF Atomics (Canada), Ltd., a subsidiary of American Machine and Foundry Co. The 36,000-sq.-ft factory will (a) produce fuel elements for NRX and NRU, (b) develop new kinds of fuel rods and (c) conduct research into nuclear work generally.

Recovery process developed by scientists of the Saskatchewan research council may lead to the mining of Canada's vast reserves of low-grade uranium ore. Dr. A. B. Van Gleave, a University of Saskatchewan Professor of Chemistry, said there was a definite possibility the process could be used commercially within a few years. Already low-grade ore is being handled in a pilot plant making use of the flotation method; the machine can process from 50 to 100 lb of uranium per hour.

Czechoslovakia

First Czech reactor became critical on September 24. Of 2 MW capacity, it will be used for the production of radio isotopes. The reactor is located at the new Institute of Nuclear Physics at Rez, near Prague. The Czechs are hoping to construct a nuclear power station soon, according to Ceteka, the official news agency.

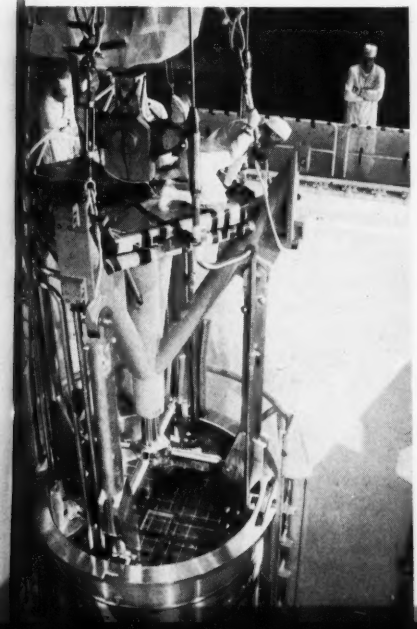
France

Saclay—France's nuclear research centre—was evacuated on October 7 following the explosion of a bottle containing a toxic gas. Three hours later the area was declared safe.

Keel of a new 55,000-ton liner, *France*, which may eventually be nuclear-powered, was laid at St. Nazaire on October 7. This luxury ship is to be launched in 1959; it will be ready for Transatlantic service in 1961.

Germany

Deve'opment of nuclear energy may be delayed by difficulties that have arisen over the building of a research reactor at Kahl, in south Germany, by the Rheinisch-Westfälische-Elektrizitäts-Werk A.G. The reactor is based on an American design which is now reported to have been declared a prototype for the U.S. atomic energy programme. The Americans are said to have stipulated that the German reactor should not come into operation before the American model. In addition there are political difficulties over the responsibility for the fissionable material due to be delivered by the United States A.E.C. under an agreement signed in July. If the contract falls through, a consortium of three companies will be affected—Mitchell Engineering, Ltd., of London, American Machine and Foundry, of New York, and Siemens-Schuckert A.G., of Erlangen.



(Left) Placing the 58-ton core into the pressure vessel at Shippingport. The project is a joint venture by the U.S.A.E.C. and Duquesne Light Co. Westinghouse developed the nuclear section of the plant.

Preparatory work has begun on the first East German nuclear power station, north of Berlin. The station is scheduled for commission in 1960.

Bavaria, in West Germany, has issued regulations for the protection of workers who might be exposed to radiation. They will have a 35-hr week and a minimum holiday of one month per year. Bavaria is the first W. German State to legislate in this way. The Federal Parliament has resisted attempts to bring in a law for the whole country.

Italy

Parliamentary ratification of the European common market and Euratom treaties was carried with a large majority in the Senate on October 9.

Japan

Fifth International Trade Fair takes place at Osaka from April 12 to 27. One section will deal with nuclear power equipment. U.K. companies interested in participating should make application through their local agents before November 30.

Toyo Zirconium Co., has started work on a new factory in the Saitama prefecture. The rated capacity is 30 tons of zirconium per month and the entire output will be sold to the U.S.A.E.C.

Mauritius

Central Electricity Board at Curepipe is seriously considering the purchase of a nuclear power station. The general manager of the Board is Mr. A. N. Bott, M.I.E.E., M.I.M.E.

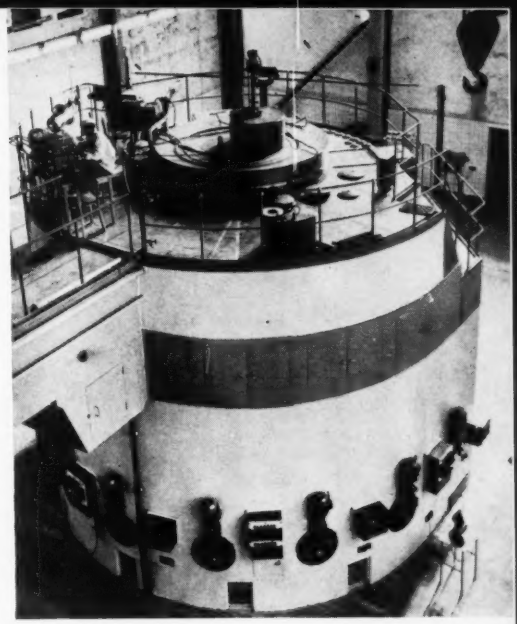
Poland

Team of eight specialists, headed by Professor K. Akerman will carry out an analysis of Poland's uranium ore deposits. The team has been formed by the Government Plenipotentiary for the Utilization of Nuclear Energy and the Minister of the Metallurgical Industry. A report will be submitted by February, 1958 giving preliminary technological data and estimates covering the cost of producing metallic uranium from indigenous ores.

Switzerland

British companies have already taken options to rent half of the Exhibition Palace in Geneva for the Atoms for Peace exhibition which is to run concurrently with the Second World Atomic Conference next September.

Training of all public health workers to deal with the hazards of contamination from radiation was urged by a committee of the World Health Organization in Geneva. The committee, which met under the chairmanship of Sir Ernest Carling, has drawn up a suitable training programme.



The first reactor to operate in Czechoslovakia is a 2 MW experimental unit which will also produce radio isotopes for industrial use. It was supplied by the U.S.S.R.

U.S.A.

Thirty-one proposals have been received by the U.S.A.E.C. from architect-engineering firms for the engineering design of a natural uranium, gas-cooled, graphite-moderated nuclear power plant of 40 MW capacity. Proposals—made in response to the U.S.A.E.C.'s invitation of August 31, 1957—are now being evaluated by the Commission.

First nuclear-powered submarine to be constructed on the Pacific Coast—*Sargo*—was launched during October at the Mare Island Naval shipyard. The pressurized water reactor is similar to that of the *Nautilus*, but incorporates advances in reactor design. As a result, construction of a small craft to satisfy special Naval requirements was possible.

U.S.A.E.C.'s programme of four power reactors has received a setback recently. Within hours of A.E.C.'s acceptance of a construction estimate of $8.9 million for a reactor project at Elk River, the tenderer, American Machine and Foundry Co., revised its price to $11.7 million.

The Commission also reveals that Foster Wheeler Corporation has increased its construction price from $5.4 million to $14.4 million on a plant to be built for Wolverine Electric Co-operative of Hersey, Michigan.

OMRE—the Organic Moderated Reactor Experiment developed for the U.S.A.E.C. by Atomics International, a division of North American Aviation Inc., became critical on September 17. Located at the Commission's National Reactor Testing Station, Idaho, OMRE uses an organic fluid, a carbon-hydrogen compound called terphenyl, for the dual role of moderator-coolant.

U.S.S.R.

Lenin—the Soviet nuclear-powered ice-breaker is being prepared for launching at Leningrad.

Solar power station in course of construction in the Ararat Valley in Armenia will have a power of 1.2 MW.

Orbits in Industry

WHATEVER the outcome of the Windscale inquiry—and one hopes that the old umbrella of National Interest will not be raised unnecessarily—the AEA should get full marks for the way they handled the situation when it arose. It must have required a very considerable amount of courage to make that decision—whether to sit tight, say nothing, and take a chance on rumours flying around; or to go to town with the full safety precautions drill and risk bags of panic in the irresponsible newspapers. The PR work was exceedingly good, too. Although the decision about the milk was not made until quite late, there was a full-dress Press conference on Sunday afternoon, at which Mr. Underwood, director of public relations, presided, with Dr. McLean, chief Medical Officer, Dr. Marley, head of Health Physics at Harwell, and Mr. Farmer, the Authority's chief Safety Officer, all laid on to answer questions. Even little Mrs. Kirke, who looks after the photographic library, was there, with a sort of postcard stall of suitable pictures; all of them, including the Press boys, looking as though they hadn't been dragged from their gardens or their locals at a moment's notice. From the passionate interest shown in milk, one would almost imagine they drank it.

Gentlemen—The Press!

". . . It is the technical Press which plays a major role in bridging this gap; it is also to the technical Press that we look for the broad and intelligent exchange of ideas and information, and for the publication of the results of our individual work. I like to think of the technical Press as complementary to the journals of the learned and professional institutions, the whole constituting a shop front in which we can display our scientific wares, not only amongst ourselves but also to other scientists all over the world. . . ."

When Mr. T. E. Goldup, the I.E.E. President, spoke these words, no one was more surprised than the Press boys present. Most of them would just as soon expect to be mentioned in the Address to the Throne as the Presidential Address of any one of our senior Institutions. It was, nevertheless, a highly gratifying experience, because it is another sign of closer co-operation between us all. There was a time, not so many years ago, when the Press was, at the best, tolerated, and it is encouraging to find that we are growing more and more like the type of boys that other boys are allowed to play with.

There are, however, one or two exceptions where one is still made to feel, if one attends a meeting as a non-member, that one has gate-crashed the funeral of a very rich aunt, and that the family resents the unwarrantable intrusion on its private grief. Happily, they are few and far between and, by the natural order of this brutal world, liable to get fewer and, for that matter, farther, if they consistently reject all publicity.

Plop!

One has grown so used, in the post-war years, to a slackened tempo in building and constructional work that it comes as a pleasant surprise when something occurs really fast. Leaving nuclear power stations out of the picture, two recent examples have been brought to our notice. One is the Texas Instruments plant, briefly reviewed elsewhere in this issue. This factory was built within seven months of the plans being approved in January, and had grown its first crystal by August 22.

The other, although on a smaller scale, was also a notable achievement. A. C. Wilson and Partners Ltd., specialists in design and procurement of remote handling installations, found that their Ealing headquarters was bursting at the seams and cast around for extra accommodation for their expanding staff. The premises selected, a billiards hall over a row of shops, were gutted, rebuilt, redecorated, relit (with something like 150 fluorescent lamps in the drawing office, replacing the cloistral gloom preferred by the previous tenants) and in operation within seven weeks.

Rev. Counters

Isotopes seem to have little in common with the ordinary domestic electricity meter, but, according to the Chairman's Address given to the I.E.E. (Measurement and Control Section) by Mr. H. S. Petch recently, nuclear methods will soon be allowing a simplified meter-testing procedure. By the use of a dab of radioactive paint on the meter disc with a suitable detector located outside the meter, it is a simple matter to obtain accurate timing of a single revolution. In the old days of meter testing with a stop-watch, the human error was much too large a percentage of the time of a single revolution, and it was necessary to take at least 30 revs. to keep the start-stop error within limits. (Tangent has dreary memories of nodding over meters, on hot summer afternoons, desperately trying to keep count as the black spot whirled round.) An accurate single-rev. timer was introduced some years ago in the form of a photocell which worked on a light beam popping through the anti-creep hole in the disc. This had, however, its disadvantages; not all meters have anti-creep holes in the discs (possibly relying on the iron filing stuck on with shellac that was customary in Tangent's day?) and it necessitated the use of a special cover to contain the light source and the photocell. The radioactive method should be applicable to any meter at any stage of its life—even in the dark cupboard under the stairs—and might, eventually, lead to semi-automatic testing and the gradual disappearance of meter testers as a separate sub-species of human being. (This is quite distinct from a separate species of sub-human being. After all, Tangent was once one of the brotherhood, and the only reason that he got away, if the truth be told, is that he wasn't awfully good at it!)

Unfair to Scriptwriters

Nature has a habit of copying art, according to one authority—but we cannot remember whom. (All we know is that it wasn't Corot, who merely complained that Nature was too green, and that the lighting was bad.) It was, nevertheless, a little hard to read the following in a perfectly straight technical paper, given by Messrs. Bush and Malott (Kaiser Engineers) on the occasion of the official opening of the ETR reactor.

. . . The supplier had one of only two machines in the country that could machine this item, had only one man who could work the machine to the degree of accuracy required for this job, and his delivery schedule affected delivery of the entire vessel. On June 5, last year, our expediter assured himself that everything was going smoothly at the vendor plant. On June 9, the expediter revisited the shop and found the machine sitting idle. When he asked the superintendent why no work was being done on our job, the superintendent told him the machinist had just completed twenty years of service, and in keeping with company policy, he had started a three-week vacation. At times like that, those of us on the project are grateful for being able to work in the San Francisco Bay area where one has the choice of three convenient and beautiful bridges off which to jump.

If real life is to be allowed to pinch the plots of all the good stories about Ministries, Royal dockyards and the nationalized industries, without anyone's permission, it does not seem quite fair to cartoonists, radio scriptwriters and people like

Tangent

Personal

Appointments

Sir James Chadwick.

Mr. A. R. Cooper.

Mr. E. J. Turner.

Sir James Chadwick, F.R.S., M.Sc., Ph.D., has been appointed by the Prime Minister as a part-time member of the U.K. Atomic Energy Authority in succession to the late **Lord Cherwell.**

Mr. A. R. Cooper has been appointed by the Minister of Power as a full-time member of the Central Electricity Generating Board. **Mr. R. R. B. Brown,** chairman, Southern Electricity Board, and **Mr. T. M. Ayres,** chairman, North-Eastern Electricity Board, have been appointed members of the Central Electricity Authority until the end of the year. **Mr. E. J. Turner,** assistant secretary, general administration, at C.E.A. headquarters in London, has been appointed secretary of the Generating Board. **Mr. A. Chorlton** as system design and development engineer at Authority headquarters. **Mr. D. F. Grant** as chief generation engineer (operation), North West, Merseyside and North Wales Division of the C.E.A.

Sir Roy Dobson, C.B.E., Hon. F.R.Ae.S., J.P., a director of Hawker Siddeley Group, Ltd., as deputy chairman of the British Group, Ltd.

Mr. Lewis Chapman as president-elect of the British Iron and Steel Federation in succession to the late **Mr. Gerald Steel. Sir Andrew McCance** has been invited to continue in office as president for 1958.

Mr. W. G'ass, managing director of Johnson and Phillips, Ltd., has also been appointed chairman. He succeeds **Mr. G. Leslie Wates** who has resigned owing to ill-health. Mr. Wates continues as a director and assumes the honorary office of president.

Mr. F. Bull as a director of Electrothermal Engineering, Ltd.

Mr. T. E. Goldup, C.B.E., M.I.E.E., technical director of Mullard, Ltd., as president of the Institution of Electrical Engineers.

Sir Alexander Fleck, chairman of Imperial Chemical Industries Ltd., becomes president of the British Association for 1958.

Dr. J. M. Dodds, O.B.E., M.A., B.Sc., B.Sc.(Eng.), Dr.Ing.(Aachen), as manager of the research department of Metropolitan-Vickers Electrical Co. Ltd. **Mr. B. G. Churcher,** who was the previous manager, will continue to act in an advisory capacity.

Mr. P. O'B. Hove, B.Sc.(Eng.), A.M.I.E.E., A.M.I.Mech.E., as Resident Manager, Middle East, of Metropolitan-Vickers Electrical Export Co. Ltd.

Dr. J. F. Shannon, Ph.D., M.I.Mech.E., as chief engineer, gear engineering dept., Metropolitan-Vickers Electrical Co., Ltd. **Mr. W. C. Clegg,** assistant purchasing agent, as purchasing agent for Met-Vick following the retirement of **Mr. G. T. King.**

Mr. R. C. Herbert, Press officer of the Department of Scientific and Industrial Research, has joined the press office at U.K.A.E.A. Headquarters.

Mr. A. J. Peech as general managing director of the United Steel Companies in succession to the late **Mr. Gera'd Steel. Mr. R. P. Crawshaw** becomes general sales manager of United Steel.

Lt.-Col. C. P. Dawnay, C.B.E., M.V.O., as a director of Electric and Musical Industries, Ltd.

Dr. James Reekie, B.Sc., Ph.D., A.M.I.E.E., F.R.S.E., as chief engineer to Semiconductors Ltd.

Mr. J. H. Bromfield as a director of the English Steel Corporation, Ltd. **Mr. J. C. Mather** has relinquished his seat on the Board.

Mr. H. T. Cadbury-Brown as consulting designer to the Turners Asbestos Cement Co., Ltd., a member of the Turner and Newall organization.

Mr. C. F. Pagnamenta as chief accountant of the Guest Keen Iron and Steel Co., Ltd., and its subsidiaries.

Mr. A. M. Taylor as director, Foster Transformers, Ltd., a subsidiary of Lancashire Dynamo Holdings, Ltd.

Mr. J. A. Shelton as sales engineer for the transistorized electronic equipment made by Venner Electronics, Ltd.

Mr. J. W. Plowman and **Mr. D. Handley** as directors of Dewrance and Co., Ltd., **Mr. F. F. H. Halestrap,** who has been with the company for over 59 years, has resigned.

Mr. A. R. Blanchard, A.M.Brit.I.R.E., as manager, industrial electronics division, **Mr. F. G. Totty** and **Mr. R. Shaw** as technical representatives for Yorkshire and E. Lancashire respectively, and **Mr. K. Adams,** B.Sc.(Econ.), takes charge of statistics and market research for Fielden Electronics, Ltd.

Colonel A. E. Tyler, O.B.E., as general manager of W.S. Electronics (Production) Ltd., and W.S. Electronics (Extruder) Ltd. **Mr. G. C. Wheeler** and **Mr. J. Wolfe** have resigned from the boards of these companies.

Mr. D. Jubb as a technical director of Modern Engineering (Bristol) Ltd.

Mr. J. D. Haight as director of Far East and Middle East area sales for Westinghouse Electric International Company.

Mr. J. J. Flaherty, formerly manager of the U.S.A.E.C.'s Chicago operations office, as assistant to Dr. Chauncey Starr, general manager of Atomics International, a division of North American Aviation Inc.

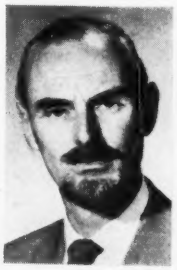
Mr. W. G. Fockler as manager of technical products engineering at Allen B. du Mont Laboratories, Inc.

Mr. Laurence S. Rockefeller, president and director of Rockefeller Bros., Inc., and **Mr. Robert W. Parcell,** business adviser to Rockefeller Bros., join the board of the Vitro Corporation of America.

Mr. Pierre Hazebroucq as commercial manager of the Compagnie d'Applications et de Recherches Atomiques (C.A.R.A.), 45 avenue Kléber, Paris.

Dr. Peter Fortescue as chief research and development engineer at General Atomic Division of General Dynamics Corporation.

Mr. T. E. Goldup.



Dr. P. Fortescue.

Mr. J. J. Flaherty.

Appointments (contd.)

Mr. A. S. Clarke, president of Nems-Clarke company of Silver Spring, Md., as director of the Vitro Corporation of America. Nems-Clarke became a Vitro division on September 1.

Mr. Philip Gomez as marketing training manager, and **Mr. Donald R. Burrus,** as marketing research manager of Texas Instruments Incorporated.

Mr. Charles E. Prior to the board of Western Gold and Uranium, Inc., U.S.A.

Mr. George D. Keller as chief engineer of Brooks Rotameter Company, Lansdale, Pennsylvania.

Tours

Mr. L. A. Rochefort and **Mr. A. C. Cooper,** chief executives of I.T.D., Ltd., travelled to the U.S.A. on September 17 to visit units of Clark Equipment International C.A. consequent upon the recent acquisition of a third interest in I.T.D., Ltd., by Clark.

Mr. C. W. Sharp, managing director of Electro-Hydraulics, Ltd., and Conveyancer Fork Trucks, Ltd., is on a three-month world tour of the company's interests in Canada, New Zealand, Australia, with calls at Singapore, Rangoon and Calcutta on the return journey.

Obituary

Nuclear Engineering records with regret the deaths of the following personalities: **Mr. J. H. C. Spinks,** M.I.E.E., who was in charge of induction motor design at Metropolitan-Vickers Electrical Co., Ltd.

Mr. Arthur Willis Fitz, B.Sc.(Eng.), A.M.I.C.E., A.M.E.M.E., F.G.S., F.R.S.A., chief planning engineer, The Nuclear Power Plant Co, Ltd., died on October 8. Mr. Fitz was responsible for the erection planning and the co-ordination of site services and equipment at Bradwell nuclear power station. He joined N.P.P.C. from the National Coal Board in 1955.

Industrial Notes

Agreements

Lee Guinness Ltd. of Newtownards, N. Ireland, have concluded an agreement with Voigt and Haeffner of Frankfurt am Main to permit the incorporation of V and G designs of contactors in automatic control gear made by Lee Guinness. This is in addition to the recent agreement with A.S.E.A. of Sweden.

Winston Electronics Ltd. of Shepperton, Middlesex, have been appointed sole U.K. agents for industrial electronic control instruments made by Beckman Instruments, G.m.b.H., Munich, Germany, and Beckman Instruments Inc., of Fullerton, California, U.S.A.

Consolidated Pneumatic Tool Co., Ltd. of 232 Dawes Road, London, S.W.6, are to manufacture under licence from the Elliott Company, a division of the Carrier Corporation, of Springfield, Ohio, U.S.A., a complete range of Lagonda tube-cleaning equipment, including cutter heads and boring tools.

North-Jomac Ltd., has been formed as the result of a merger between James North and Sons, Ltd., and James North Export, Ltd., and Jomac Inc., of the U.S.A. James North are already supplying very large quantities of p.v.c. gloves to U.K.A.E.A. factories and the merger will assist the marketing of similar products in the United States.

Solartron Electronic Group Ltd., Thames Ditton, Surrey, is now the U.K. sales and service agent for electronic measuring instruments made by Schomandl, K.G., Munich.

Elesco Electronics Ltd. of 2 Fitzroy Place, Glasgow, C.3, have been appointed sole agents in Scotland for all products of Southern Instruments Computer Division, Frimley Road, Camberley, Surrey.

Contracts

Wakefield-Dick Industrial Oils Ltd. have been appointed by U.K.A.E.A. as suppliers of lubricants for Chapelcross nuclear power station.

Elliott Bros. (London), Ltd., have just delivered an analogue computer to the nuclear research laboratories of C. A. Parsons, Ltd., Newcastle upon Tyne. This computer, which has been specially built to supplement the facilities of a larger machine designed by C. A. Parsons themselves, and already in use, will be mainly devoted to studies on control systems for nuclear power stations. Based on the standard Elliott G-PAC (general purpose analogue computer) form of construction the new computer, which has been completed by the Company's nuclear division, includes eighteen drift-stabilized D.C. amplifiers, nine high-speed servomultipliers and a square-root function generator.

Expansion

Metropolitan-Vickers Electrical Co., Ltd., have extended their apprentice training school premises at the Trafford Park works.

A. C. Wilson and Partners Ltd. have opened a new design office to house 100 engineers and draughtsmen about half a mile from their main offices at Design House, The Mall, Ealing, W.5, which already house more than 100. The company, which is associated with the Power-Gas Corporation, has several nuclear projects on hand including an irradiated fuel element laboratory for Windscale, an experimental loop breakdown cave, a fuel element pond facility and a blanket stripping cave, the last three being for Dounreay.

Miles Electronics Ltd. is the title of a new company formed on October 7. The company is at present mainly concerned with the production of flight simulators.

G. L. Willan Ltd., have opened a new high vacuum metallurgical department at their Sussex Street, Sheffield, premises. The department has a 50 kW 56 lb capacity high vacuum melting installation supplied by the Efco-Edwards Vacuum Metallurgical Co., Ltd., for the production of special high duty steels on a commercial basis.

During a recent series of open days, a large number of industrialists were able to see some of the work in progress at the new Mullard research laboratories at Salfords, Surrey. A further 18,000 sq ft has been made available by the new block shown here.

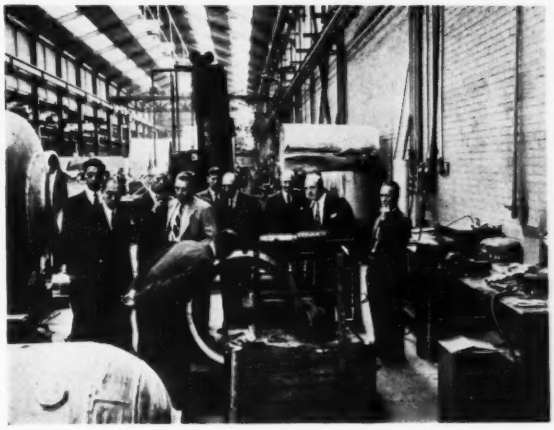
CAPI—Consultants in Atomic Power and Industry—have received a commission from an organization overseas to act on their behalf in the assessment of nuclear power station designs. The company would be pleased to receive, direct, literature from component manufacturers. Offices are at 34 Sackville Street, London, W.1.

Joseph Sankey and Sons, Ltd., have been awarded a £1¼ million contract by the Governing Board of the National Institute for Research in Nuclear Science for the magnet yoke of a new 700 MeV proton synchrotron. The accelerator is now in course of erection on a site adjacent to A.E.R.E., Harwell. Sankey will supply 340 steel blocks, each weighing 20 tons. The special steel required will be provided by the Steel Company of Wales, Ltd.

Texas Instruments Inc., of Dallas, Texas, announces price reductions of 22% on silicon transistors and 35% on silicon glass diodes.

Head Wrightson Processes Ltd. will collaborate with Land-Nordrhein-Westfalen in the design and engineering of a materials-testing reactor similar to DIDO. This is the sixth reactor order awarded to Head Wrightson and the third for export. U.K.A.E.A. will supply the enriched fuel elements.

The Mond Nickel Co., Ltd. are sponsoring an exhibition of their products at the Royal Station Hotel, Newcastle-upon-Tyne, from November 5 to 8. Particular attention will be paid to the uses and development of nickel, nickel alloys and related materials.



Members of the South London branch of the Institute of Welding saw 1¾ in. thick aluminium sections being welded at the A.P.V. works at Crawley during a recent visit.

Bribond Ltd. is the new name for Brighton Laminations Ltd., a member of the Ayling Industries group. The company has just moved to a new 10,000 sq ft factory at Burgess Hill, Sussex. Products include thermosetting and thermoplastic labels, diagrams, printed circuits and mouldings.

The A.P.V. Co., Ltd. were hosts to members of the South London branch of the Institute of Welding and a party of engineers from H.M. Dockyards, Portsmouth, during September. Both parties were shown the company's advanced methods of welding large aluminium and stainless steel vessels.

Constructors-John Brown Ltd. is the new name for Costain-John Brown Ltd. The company is now a wholly-owned subsidiary of John Brown and Co. Ltd.

Brochures

Tornado 4-way Welding Fume Exhaust Unit.—Publication No. 38 describes an equipment for disposing of welding fumes from up to four positions. Keith Blackman, Ltd., Mill Mead Road, London, N.17.

David Brown Varicon.—A stepless speed reducer. Size 5 caters for drives up to 5 b.h.p. David Brown Corporation (Sales) Ltd., Radicon Division, Park Works, Huddersfield.

Review of Power Reactor Systems.—A new bulletin, GER-1384 presents a detailed picture and word description of various systems using water, gas, sodium and liquid fuel as coolants. General Electric Apparatus Sales Division, Schenectady 5, New York.

Welding Fittings.—Fittings matching American and British standard pipes are described in two separate leaflets issued by B.K.L. Alloys Ltd., Kings Norton, Birmingham 30.

The Isotope Index.—A purchasing guide to the whole range of Isotopes available. 100 pages, $3.50, post paid from Scientific Equipment Co., 23N, Hawthorne Lane, Indianapolis 19, Indiana.

Engineering for Atomic Power.—Colourful 40-page booklet outlining the part played by Stone and Webster in nuclear development. Stone and Webster Engineering Corporation, 90 Broad Street, New York.

Isotope Transporting Cans.—Lead containers to A.E.A. specifications together with handling tools. Savage and Parsons Ltd., Watford, Herts.

Refrasil.—A lightweight fibrous silica material capable of withstanding continuously temperatures of 1,000° C. British Refrasil Co. Ltd., Stillington, Co. Durham.

Platinum Metals Review.—Vol. 1, No. 4 contains a short article on platinum equipment used in plutonium extraction at Windscale. Johnson Matthey and Co. Ltd., 78 Hatton Garden, E.C.1.

Heavy Alloy for Industry.—In addition to its mechanical application, its use in the nuclear field as a shielding material is very thoroughly covered and there is a series of shielding characteristic curves showing comparisons with lead for various isotypes. The General Electric Co. Ltd., Osram Metals Division, East Lane, Wembley, Middlesex.

Films

Manipulation of Corrosion and Heat Resisting Steels.—A new film recently made by Firth-Vickers Stainless Steels, Ltd., giving instruction on what to do and what not to do with stainless steels, with examples of forming and fabrication processes from preparation to final polishing. In 16 mm. Kodachrome, running time 30 minutes.

Where Staybrite Steels are Made.—The latest Firth-Vickers film showing the manufacture of more than 40 types of stainless steels from the rough ingot onwards, including rolling, centrifugal and precision casting. The new continuous rolling mills are shown producing continuous strip in 5-ton coils. In 16 mm. Kodachrome, running time 28 minutes. Both films are available on loan from Firth-Vickers Stainless Steels, Ltd., Staybrite Works, Sheffield, 9.

British Atomic News, the film recently completed by Mr. B. Charles Dean, is to be distributed overseas by the Central Office of Information. The film, in Eastmancolour, was shown at the Festival of Films in the Service of Industry at Harrogate and at the *Sunday Times* "Atom, 1957" exhibition in London during October.

U.K. Atomic Energy Authority Films.—Because the Authority is committed to train British industry in the techniques of building nuclear reactors for power production a series of films was commissioned to describe the contruction of both Calder Hall and the fast reactor at Dounreay. Starting in the earliest days at Calder Hall, cameramen filmed every important stage in construction. One of the first jobs was to pour the concrete for the raft on which each reactor stands. As the work went on the cameramen took their equipment to precarious perches on crane jibs and girders and into confined spaces inside the reactor pressure-vessels. They eventually completed a unique film record, including shots of the lifting into position of the 200-ton heat-exchangers and the laying of graphite blocks forming the reactor cores. A similar film record has been made of the new fast breeder reactor and its spherical container at Dounreay in the North of Scotland. The filming was carried out on behalf of the Authority by Ace Distributors, Ltd., 14 Broadwick Street, Wardour Street, W.1 (Telephone: GERrard 3165), from whom 35 mm. and 16 mm. copies can be obtained on loan, free of charge. Titles of films immediately available are: "The Construction of Calder Hall," 40 min.; "Heat Exchangers at Calder Hall," 28 min.; "Engineering at Calder Hall," 39 min.; and "The Dounreay Sphere," 35 min.

Forgemasters in Steel.—The latest E.S.C. colour film traces the part played by the company in the history of steel forging and then deals with present-day processes. It contains excellent shots of steel melting and teeming, the casting of large ingots and their subsequent forging and testing. English Steel Corporation, Ltd., River Don Works, Sheffield.

Meetings

October 29.—"Some Aspects of the Large-scale Use of Irradiation in Industry," by R. Roberts, before a meeting of the Institution of Chemical Engineers, North Western Branch, Blossoms Hotel, Chester, at 7 p.m.

November 5.—Presidential address by Sir Arthur Whitaker before a meeting of the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, at 5.30 p.m.

November 5.—"The Design of the Control Unit of an Electronic Digital Computer," by M. V. Wilkes, M.A., Ph.D., F.R.S., W. Renwick, M.A., B.Sc., and D. J. Wheeler, Ph.D.; "A Decimal Adder Using a Stored Addition Table," by M. A. Maclean, M.Sc., and D. Aspinall, B.Sc.; "An Accurate Electroluminescent Graphical Output Unit for a Digital Computer," by T. Kilburn, M.A., Ph.D., D.Sc., G. R. Hoffman, Ph.D., B.Sc., and R. E. Hayes, M.Sc., before a meeting of the measurement and control section of the Institution of Electrical Engineers, 2 Savoy Place, London, W.C.2, at 5.30 p.m.

November 7.—"Atomic Energy—the Management of a New Industry," by Dr. H. Rogan, works general manager, Springfields Works, U.K.A.E.A., before the National Management Conference of the British Institute of Management, Bournemouth, at 9.30 a.m.

November 12.—"Washing of Solids," by J. E. Grew and P. K. Williamson, before a meeting of the Chemical Engineering Group at the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1, at 5.30 p.m.

November 19.—Two papers on pressure vessels by R. W. Lakin and A. N. Other, before a meeting of the North Western Branch, Institution of Chemical Engineers, at Reynolds Hall, College of Science and Technology, Manchester, at 7 p.m.

November 20.—"Fabrication, Erection and Welding of Dounreay Sphere," by J. A. Forrest, A.M.I.Mech.E., and James McClean, B.Sc., A.R.T.C., before a joint meeting of the Scottish branch of the Institution of Structural Engineers and the West of Scotland branch of the Institute of Welding, at the Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, Glasgow, at 7 p.m.

Processes and Equipment

Cooling Water Studies

Both the new nuclear power stations, Berkeley (on the estuary of the River Severn) and Bradwell (on the estuary of the River Blackwater) present cooling problems because of the large volumes of water required. To investigate the conditions involved special scale models have been constructed by the Central Laboratory of George Wimpey and Co., Ltd.

The investigation was made at the instigation of Rendel, Palmer and Tritton, consulting engineers to the C.E.A. The work involved the design and construction of hydraulic models of parts of the two estuaries, so that different arrangements of outfall and intake could be investigated under varying conditions of the tidal cycle.

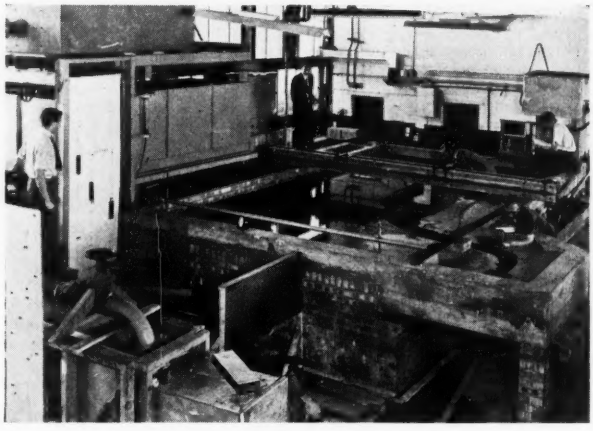
The area of estuary bed—which was accurately reproduced from detailed hydrographic surveys—was kept to the minimum consistent with validity of simulation of tidal currents. The latter were calibrated from float tests made on site and, as the small area of the model surface relative to the discharge made flow conditions over the surface very sensitive to small changes of shape, this phase of the operations called for much patience and care.

The general hydraulic arrangements were virtually common to the two models, but the ripping out of one model surface and moulding of the other, with all details accurately to scale, in a little over one week-end were nevertheless noteworthy.

The horizontal scales for the Berkeley and Bradwell models were 25 ft. and 16 ft. to 1 in. respectively. Vertical scales were 5 ft. to 1 in. in both cases. As it was unnecessary to repeat more than one semi-diurnal cycle of the tide at a time, control was manual. Water flowed continuously from the metering tanks into the brickwork tank containing the moulded surface and thence to the sump for re-circulation round the system. By arranging valves so that more or less water flowed out of the tank than flowed into it, a falling or rising tide was produced. Flow across the moulded surface to simulate the corresponding ebb and flood of the tide in the estuary was produced by continuous adjustments of a tilting chute which discharged to one end or other of the models.

Warm water was discharged from modelled outfalls while corresponding quantities of water were drawn off at modelled intakes of the power station circulating water system. Temperatures at different points on the model were read to an accuracy of 0.1°F at half-minute intervals throughout a tidal cycle.

(George Wimpey and Co., Ltd., Central Laboratory, Bullsbrook Road, Springfield Road, Hayes, Middx.)

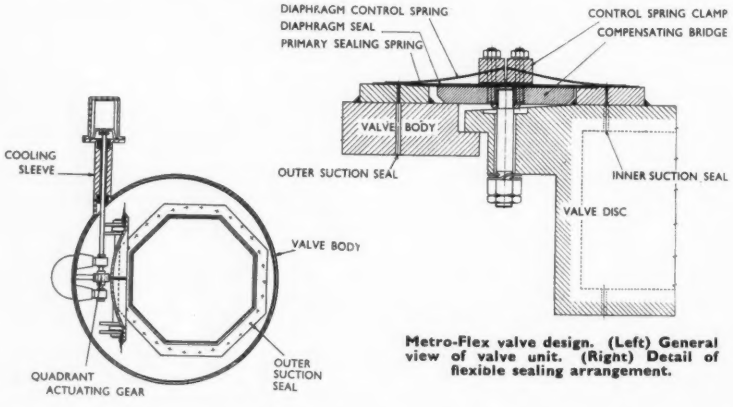


General layout of the Bradwell model for studying coolant flow at Wimpey's Central Laboratory.

New Valve Design

A new range of Metro-Flex valves for gas circuits is at present being developed by Metropolitan Combustion Engineering Ltd., of 47 Whitechapel High St., London, E.1. The philosophy underlying the design is, quite simply, that any conventional design of large valve, no matter how well designed or stoutly constructed, will distort, and that the best way of obtaining a permanent 100% gas-tightness is to utilize a plain flap valve surrounded by a flexible seal, to accommodate distortion, thus applying the principles used for many years in the sealing of large flue dampers on conventional steam installations.

The general arrangement of the complete valve and of the seal are shown in the accompanying illustrations. As may be imagined, a plain, unsupported flexible metallic strip would be impracticable since it would inevitably be damaged by the differential pressure. The construction adopted utilizes a "compensating bridge" surrounding the valve disc and overlapping the gap; this is spring mounted so that it offers a semi-rigid support for the actual thin metal sealing strip. A series of small holes through the seating on both sides of the joint provides a suction seal, tending to pull the flexible strip more firmly down on the seating. It is stated that this type of valve lends itself to glandless operation.



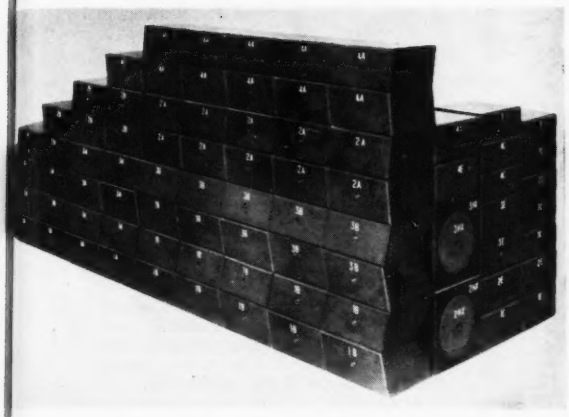
Metro-Flex valve design. (Left) General view of valve unit. (Right) Detail of flexible sealing arrangement.

Servo Units

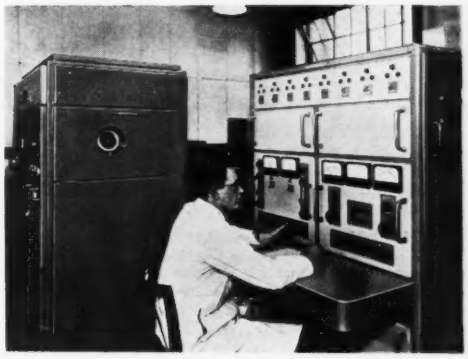
A range of servo units with considerably improved power to weight ratio was recently introduced by Harvey Electronics Ltd. The smallest version of the series measures 3.5 in by 2.1 in by 1.35 in. It has a stalled torque of 1 lb/ft; the rate of response is 60°/sec on no load and the accuracy of repeatability is 0.1% full scale.

These units should prove suitable for inclusion in remote-handling equipment or any similar application where a compact power source is required.

(Harvey Electronics Ltd., Farnborough Road, Farnborough, Hants.)



(Left) Cast iron shielding blocks to a specification calling for a maximum porosity of 3% were recently made by Newburgh Engineering.



(Right) Met-Vick MS7 mass spectrometer as supplied to the BTH research laboratories, Rugby.

C.I. Shielding Blocks

Newburgh Engineering Co., Ltd., recently manufactured a large quantity of cast iron biological shielding blocks for installation at Harwell (PLUTO) and Dounreay (DMTR). Approximately 15½ tons were supplied to each establishment under a sub-contract from Head Wrightson Processes, Ltd.

Newburgh state that no specific grade of C.I. was called for although the blocks had to comply with a specification allowing a maximum porosity of 3%. Every block was therefore radiographed before machining and after final machining was subjected to a gamma penetration test using a 1021 B monitor Co^{60} isotope and scintillation counter. All blocks tested were within the 3% porosity limit.

(Newburgh Engineering Co., Ltd., Newburgh Works, Bradwell, near Sheffield.)

Analysing Inorganic Solids

Two special kinds of mass spectrometer have been designed by Metropolitan-Vickers for the analysis of inorganic solids—the MS5 for the determination of isotope ratio using the surface ionization technique, and the MS7 for the analysis of impurities using the spark ionization technique.

The MS5 is a 12-in.-radius 90°-sector single-focusing mass spectrometer for use with either the single- or triple-filament surface ionization technique. Two particular features of the instrument are (i) a sliding-bar vacuum-lock system, which enables the sample to be introduced into the instrument in less than a minute, and (ii) an ion collector system, which provides for the simultaneous availability of a normal collector (noise level approx. 3×10^{-15} A) and an electron multiplier (equivalent noise level less than 10^{-18} A). A resolving power of at least 300 can be obtained.

The type MS7 mass spectrometer is designed for the general analysis of solids by the spark ionization technique. It is a double-focusing instrument of the Mattauch type, in which positive ions, representative of the same composition, are produced when a high-voltage spark occurs between two electrodes formed of the sample material and placed close together in vacuum. After passing first through an electrostatic analyser and then through a magnetic analyser the ions come to focus according to their mass as a series of lines on a photographic plate.

The method is particularly useful for giving a general picture of the impurities in a solid. The whole mass range from 7-240, covering all elements, can be recorded in a single exposure of the photographic plate. Compared with emission spectroscopy the spectra are simpler and the elements easier to identify. Moreover, qualitative and semi-quantitative analyses can be carried out without extensive calibration.

(Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17.)

Brookhirst Switchgear have supplied this switchboard to Laurence Scott and Electromotors, Ltd., for installation at Dounreay, where it will be used for actuating control, safety and shut-off rods.

New Stainless Steel

Firth-Vickers Stainless Steels, Ltd., of Staybrite Works, Sheffield, 9, announce 520 stainless steel, on which they have been working since 1953.

FV 520 has a typical analysis of 0.7% C, 16% Cr, 6% Ni, 1.5% Cu, 1.5% Mo and 0.3% Ti. Intended to bridge the present gap in the stainless steels, it combines the corrosion resistance of the 18/8 steels with the facility of heat treatment and consequent high tensile strength of those alloys which do not possess the same resistance to corrosion and are not easily welded. In addition to its weldability, the advantages claimed are high tensile and fatigue resistance; stainless properties equivalent to 18/8 steels; resistance to stress corrosion cracking; good notch-impact results at low temperatures; and, last but not least, thermal expansion characteristics comparable with mild steel. It is suitable for operating conditions with a ceiling temperature of 500° C (approx. 933° F) and is supplied in two forms. Sheet and strip material which require forming operations are supplied in a form on the border between the austenitic and martensitic forms, so that press-work, etc., can be carried out in a softened condition prior to heat treatment. With bar material, castings, and forgings, it is unnecessary to allow for this, and the material is not supplied with any austenitic characteristic. The new steel is the subject of patent applications 26796/54 and 24990/56.

BRIEFLY . . .

Weatherfoil Ltd., of 185 Bath Road, Slough, Bucks, has created an air treatment division which will work closely with the existing heating and industrial divisions to provide a full technical advisory service on factory conditions.

Ketay Ltd. announce that their synchro control transformer, type 15CT4a, has received type approval from the Ministry of Supply.

General Electric, of U.S.A., has developed a closed-circuit three-dimensional colour television system for the remote servicing of reactors and critical assemblies developed for an aircraft propulsion system. The new system permits the use of colour-coded components and facilitates positioning.

Whades (Sussex) Ltd., of Duke Street, Littlehampton, Sussex, have introduced a lightweight trolley, the Miniveyor, powered by a Villiers 147 c.c. two-stroke engine. The trolley has automatic transmission and costs £92 10s.

Henry Wiggin and Co., Ltd., announce that the name Nimocast is being used to describe a range of high-temperature nickel-chromium-base alloys for use in the cast form. The Nimocast alloys are complementary to the Nimonic series of wrought heat-resisting alloys.

Kelvin Hughes Ltd., have developed a vacuum seal which solves the problem of re-closing a gas-tight container after wires have been passed through the case. Fine-drawn copper tubes partly filled with solder are led through the neck of a brass ferrule and potted into position with a synthetic resin. The wires are then soldered to the tubes.

Liquid Systems Ltd., of Norwich Union House, Wellesley Road, Croydon, are manufacturing the Bowser Fig. 280 floating suction under licence. The equipment is designed for applications where it is necessary to draw liquid from the surface rather than the bottom of the storage tank.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 776,371. Cold drawing of titanium or titanium base alloys. I.C.I. Ltd., S. Hands, J. Humpage.

The high coefficient of friction between titanium and the die materials makes drawing difficult. This difficulty is overcome by providing the rod, wire, tube or the like to be drawn with an anodically produced coating from an electrolyte of orthophosphoric acid (80%), sulphuric acid (10%) and water (10%).

B.P. 776,617. Dispensing apparatus for liquids. J. Waddell, H. F. Parker, H. Haselden. To: U.K. Atomic Energy Authority.

The problem of sampling radioactive liquors is one of minimizing radiation and avoiding spilling (contamination). A small-capacity reservoir, which can be flushed with liquid and then filled to a predetermined level carries a hypodermic-type needle with its unpointed end open to the reservoir below that level and its pointed end exposed above it. A rubber-capped evacuated bottle of greater capacity than the volume of liquid in the reservoir can be advanced and withdrawn on to and away from the needle which thereby penetrates the cap and injects liquid into the bottle. The sampling machine has a row of sampling points and a mechanism for bringing a bottle over these points by means of a long pair of curved tongs and mirror viewing through periscope behind a shielding wall.

B.P. 776,649. Alloys of magnesium. R. A. U. Huddle, J. Laing, A. C. Jessup, E. F. Emley. To: U.K. Atomic Energy Authority.

An alloy of high magnesium content, 0.008 to 0.1% beryllium and 0.25% aluminium. Calcium may also be present (0.02 to 0.44%). The alloys could be melted in their oxide skin in air without taking fire, e.g., for aircraft landing mats.

B.P. 776,739. Manufacture of titanium. J. J. Gray. To: I.C.I. Ltd.

A commercially useful rate of producing titanium metal by reduction of titanium tetrachloride with sodium without a dangerous rise in the temperature of the reaction mass is maintained by arranging conditions so that part of the heat of reaction is dissipated by vaporizing a proportion of the molten sodium. The vapour is subsequently condensed and the liquid metal returned to the reaction zone.

B.P. 776,802. Particle accelerators. To: General Electric Co. (U.S.A.).

The X-ray output from a particle accelerator is synchronized with the motion of a recurrently moving object in order to make a radiograph of this object. It is thus possible to obtain internal stroboscopic radiographs of machines with recurrently moving internal objects by injecting particles into the accelerator only when the cycle commences within a fixed time interval after that body reaches a triggering position whereupon an X-ray target is bombarded with these particles.

B.P. 776,865. Coating metals. R. L. Samuel. To: Diffusion Alloys Ltd.

A molten metal is cast in a sand mould which has been provided with a coating of a powder containing or consisting of the metal with which the cast metal is to be coated. A fluxing medium assists the fusion of the metals. Coating metals may be chromium, zirconium, nickel, cobalt, copper and their alloys.

B.P. 777,039. Valves for controlling high-temperature fluids. F. L. Speed. To: U.K. Atomic Energy Authority.

A valve for high-temperature liquid (sodium) with a self-sealing leak-proof gland of (a plurality of) O-ring seals arranged as an insert over the spindle on a sleeve-like extension of the valve body. The extension and the spindle are of such length that combined with fins around the extension, a temperature drop is caused between the valve seat and the gland which results in liquid sodium passing through the valve becoming solid at the gland.

B.P. 777,146. Manufacture of barometric bellows and like corrugated tubes. H. W. G. Wolley. To: U.K. Atomic Energy Authority.

Uniform wall thickness of the order of 0.02 inch within a tolerance of ± 0.001 inch is obtained by forming the corrugations successively in a shaping die while the unformed part of the tube follows unrestrained axially the movement caused by the forming operation.

B.P. 777,248. Ion exchange substances. J. Kennedy. To: U.K. Atomic Energy Authority.

Refers to a cationic exchange resin of high adsorption of the uranyl ion compared with that of many common cations. It is an alphyl-allyl hydrogen phosphate polymer, the alphyl group being either allyl or a lower alkyl group (such as methyl or ethyl).

B.P. 777,402. Electromagnetic survey apparatus. To: Canadian Airborne Geophysics Ltd. (Canada).

An arrangement of receiving and transmitting coils and circuitry placed together in a single "bird" towed under a prospecting aircraft at a distance therefrom eliminating interference from the aircraft components. As the transmitting coil is remote from the aircraft it can operate much more closely to the ground surface without danger to the aircraft.

B.P. 777,420. Variable-speed gearing. K. H. Dent. To: U.K. Atomic Energy Authority.

In the movement of control rods in one type of nuclear reactor it is required that the rods are withdrawn at one tenth of the speed at which they are inserted. This can be achieved by a gearing in which the input shaft is driven by an electric motor having a sun gear fixed to the shaft and an output gear wheel meshing with a wheel fixed to rotate with a planet wheel. The planet wheel is rotatable on a carrier in mesh with the sun wheel. A mechanical freewheel device is provided between input shaft and carrier and an electromagnetic brake for restraining the carrier. A single switch with multiple contacts reverses the drive and changes the energization of the electromagnetic brake so that the reversal of the rotation of the motor coincides with the change of the speed ratio.

B.P. 777,421. Variable-speed gearing. K. H. Dent. To: U.K. Atomic Energy Authority.

Refers to an arrangement for slipping of the coupling in the gear described in B.P. 777,420 in order to make jamming of the control rods harmless by letting them fall under gravity on failure of the gear.

B.P. 777,599. Pressure vessels. A. F. G. Austin. To: Whessoe Ltd.

The connection of branch pipes to pressure vessels raises special stress problems. The problems of avoiding an abrupt change of contour and of enabling examination of the weld can be solved by the arrangement in the aperture for the branch of a ring of special shape whose outer edge is equal in thickness to that of the wall of the vessel and which is butt welded to the surrounding wall. The thickness of the ring increases smoothly from its outer edge to a value around its inner edge at a calculated ratio (stress concentration through piercing the vessel). The ring provides at or near its inner periphery a flange to be butt welded to the branch pipe.

B.P. 778,051. Separation of plutonium and uranium from fission products. J. K. Dawson, A. E. Truswell. To: U.K. Atomic Energy Authority.

Production of plutonium and recovery of uranium from neutron irradiated uranium by organic solvent extraction of the nitric acid solution of the irradiated uranium in a number of stages does not readily eliminate all fission products from the uranium and plutonium. Some products, particularly ruthenium, present difficult problems. A simple method of separating plutonium and/or uranium, especially from ruthenium and rhodium, consists in treating the metal or compound with a gaseous fluorinating agent (hydrogen fluoride; chlorine trifluoride; bromide trifluoride) in admixture with 2-10% of a gaseous oxidizing agent (air; oxygen).

B.P. 778,077. Preparation of allyl phosphites. J. Kennedy. To: U.K. Atomic Energy Authority.

A mixture of equimolecular proportions of allyl alcohol and a tertiary amine base is slowly mixed with a reacting proportion of phosphorous trichloride at a temperature in the neighbourhood of 0 deg. C or lower. The mixture is then allowed to attain ordinary temperature.

B.P. 778,192. Process for removing hafnium from zirconium. I. E. Newnham. To: Commonwealth Scientific and Industrial Research Organization.

The tetrahalides of zirconium are reducible at temperatures at which the corresponding tetrahalide of hafnium undergoes no reduction. This is the basis of the method in which the tetrahalides are heated with finely divided zirconium metal (magnesium, aluminium, zinc or other metal of sufficient oxidation reduction potential) to a temperature at which hafnium tetrahalide still remains unreduced, which can then be removed from the reaction mass.

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